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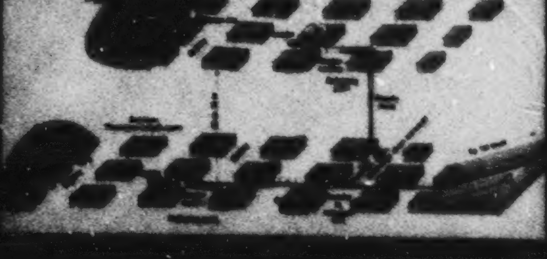
ALTERNATIVES TO PRESENT POTASH MINING PRACTICE IN CANADA

MONENCO ENGINEERING COMPANY LIMITED



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DECEMBER 1984

ALTERNATIVES TO
PRESENT POTASH MINING PRACTICES
IN CANADA

FINAL REPORT

BY

MONTREAL ENGINEERING COMPANY

December 1984

Work on this project was conducted under the auspices of the Canada Centre for Mineral and Energy Technology, Energy, Mines and Resources, Canada.

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Monenco

Montreal Engineering Company, Limited
400 Monenco Place, 801 - 6th Avenue S.W.
Calgary, Alberta, Canada T2P 3W3
Tel (403) 298-4170
Telex: 038-22636

1985-02-08

Dr. J. Pathak
CANMET
Department of Energy, Mines & Resources
Bells Corner Complex
Building 10
Haanel Drive
Nepean, Ontario

Dear Sir:

Re: Alternatives to Present Potash
Mining Practices in Canada
CANMET Project 310104 - Ref. No. 26SQ.23440-3-9124

We have pleasure in submitting our final report for the above project, in six bound copies and ten microfiche copies, and five bound copies of the executive summary in English and French.

The report, which include the comments made during the review of the draft report, contains nine parts.

Part 1 provides the background to the study, Part 2 deals with the study methods; Parts 3 and 4 describe respectively the mining methods presently in use in Canada and internationally; Part 5 summarizes the characteristics of the mining methods. The alternative mining methods which could be applied in Canada are discussed in Part 6, and the necessary geotechnical program is outlined in Part 7. Part 8 records the conclusions and Part 9 presents the recommendations for further work on this subject. Two appendices complete the report.

.../2

We have found the work on this project extremely interesting and trust that this report will be to your satisfaction. We shall be pleased to answer any questions arising from the report.

Yours very truly

Montreal Engineering Company, Limited

A.M. Scott

A.M. Scott

A.M. Scott, P.Eng.
Chief Mining Engineer

I.R. Muirhead

I.R. Muirhead, P.Eng.
Manager Mining

THE ASSOCIATION OF
PROFESSIONAL ENGINEERS
OF ALBERTA
PERMIT NUMBER
P236
MONTREAL ENGINEERING
COMPANY LIMITED

EXECUTIVE SUMMARY

(English)

1.0 INTRODUCTION

This report has been prepared by Montreal Engineering Company Limited, assisted by Minco Consultants (Geological Aspects) and Golder Associates (Geotechnical Aspects), in response to a request by CANMET to identify alternatives to the methods presently used to mine potash underground in Canada with particular reference to those aspects that could result in improved extraction ratios and/or lower mining costs.

The potash mining industry in Saskatchewan has one of the lowest mining extraction or recovery percentages in the international industry. This means that within a given area underground, the mining methods used are not able to recover more than about one third of the available ore. Other mining methods are in use where up to three quarters of the ore can be mined. It is therefore of particular interest to the Canadian potash industry for these alternative mining methods to be reviewed and an assessment made of their applicability to Canadian mining conditions.

The ability to increase the percentage of ore mined from a given area has a substantial beneficial effect on both operating and capital costs and on the operating efficiency of the mine. The mine workings are concentrated in a smaller area thus reducing transportation, ventilation and other service needs, communication and control is easier, and less development work is needed thus allowing machinery to be utilized on the more productive panel mining.

2.0 STUDY METHODS

Potash is mined by underground methods in some ten countries around the world. In addition to Canada, the second largest producer, (Table 1) these include USA, USSR, West Germany, East Germany, France, Spain, Italy, UK and China. Data was collected from this widespread area by three methods: 1) Visits to mines in Canada and the USA, 2) Issue of a questionnaire to 43 mines around the world, 3) Literature search. The bulk of the data used in the report was obtained from the mine visits, literature review and in-house data. Response to the questionnaire was minimal (14%); probably reflecting the competitive nature of the industry.

3.0 MINING METHODS - CANADA

Potash is mined in two provinces in Canada, Saskatchewan and New Brunswick.

3.1 NEW BRUNSWICK

New Brunswick is the newest of the potash producing Provinces with the first mine (PCA) coming into production in 1984, the second (Denison) due in 1985 and the third (BP) due in the late eighties.

Conditions in the New Brunswick potash are quite different to those in Saskatchewan in that the potash beds are steeper, highly folded or in dome type structures and of varying thickness. The Saskatchewan beds are of uniform thickness, regularly bedded and almost flat.

The mining methods employed or expected to be employed are also dictated by the requirement of the provincial government that no salt tailings can be stored permanently on the surface.

The one operating mine (PCA) has opted for the cut and fill method in its inclined workings and expects to obtain panel recoveries approaching 80%. The other two mines have selected the room and pillar method using long rooms and backfill to achieve panel recoveries between 40% and 60%.

Saltback cover is generally variable, ranging from a minimum of 100 m at PCA to between 10 m and 100 m at Denison and 20 to 50 m at BP. The minimum acceptable cover is 10 m at Denison and 20 m at BP.

3.2 SASKATCHEWAN

Conventional potash mining in Saskatchewan is carried out in two areas - Esterhazy and Saskatoon.

Conditions are generally better in the Esterhazy area, with salt back cover averaging 30 metres over the 2.4 m mined seam. Mining at around 960 m depth is based on the long room and pillar system having evolved from the standard room and square pillar in an effort to overcome roof control problems and low recovery. Panel recoveries now average 55%. No pillar mining takes place and overall recovery averages 35% for the two mines operating in the area.

In the Saskatoon area, there are six mines working at between 1000 m and 1150 m depth, all the mines having started with the standard room and pillar system. However, because of severe roof and floor problems caused by clay bands in the immediate strata and a much reduced salt back cover (8 to 14 m) mining methods have evolved to the present room and pillar systems with either long rooms or chevron layouts incorporating stress relief configurations. Overall recoveries range from 35% to 38%, whilst panel recoveries vary between 50% and 60%. Overall recoveries under the initial mining methods were in the 25% region.

Mining in Saskatchewan is particularly governed by depth and the strata loads imposed, and by the need to prevent the Dawson Bay aquifer on top of the saltback from being breached. Consideration of alternative mining methods have to take these two facts into account.

3.3 REGINA

The Saskatchewan potash deposits become deeper as they trend in a southwesterly direction. Thus in the Regina area, they are at a depth of 1500 m. This is too deep for conventional underground mining. There is one mine operating in this area recovering potash by solution mining through surface wells.

4.0 MINING METHODS - INTERNATIONAL

As might be expected, the methods used elsewhere around the world vary according to the nature and depth of the deposit.

4.1 USA

In New Mexico, there are five mines working the relatively flat and consistent bedded deposits at depths varying from 260 m to 550 m. Saltback cover is massive, exceeding 200 m in all cases. Mining initially developed around standard room and pillar systems, but a number of variations are also in use. One mine still practises conventional room and pillar mining with pillar recovery, achieving a 90% recovery in the panel, and 70% overall. Room and pillar on a long room or chevron pattern is used with overall and panel recoveries of 55% and 75% respectively.

Of particular interest is the shortwall mining system using narrow yielding pillars. This is being successfully used to extract over 92% of the mining panel in seams ranging from 1.2 to 1.5 m thickness, and still maintain control of the lowering of the roof. This method, suitably adapted, is of considerable interest for Canadian Potash mines.

In Utah, the potash deposits are being worked by one mine. This initially operated as a conventional underground mine using room and pillar methods, but due to severe geological and gradient conditions, it was converted to a solution mining operation. Wells were drilled from the surface into the underground workings and the potash is now being successfully and economically extracted.

In Wyoming, a trona mine was visited which was operating at a depth of 975 m. Both longwall and conventional room and pillar are being used, panel recoveries being 81% and 36% respectively.

4.2 USSR

As the largest potash producer in the world, the USSR operates mines in three different locations and conditions. The smallest proportion of output comes from the Ukraine where eight small mines produce 400,000 tonnes of K_2O per year from steep seams using room and pillar and shrinkage stoping (with backfill) methods. Panel recoveries average 78%.

In the Byelorussia region, mining at the four mines commenced based on conventional room and pillar mining of the relatively flat beds, some 350 to 620 m below the surface. However, poor panel and overall recoveries and roof control problems led, after extensive geotechnical research and mining trials to the use of longwall caving methods in single or double lift mining.

In areas where full caving cannot be accepted due to aquifers, room and pillar mining with yield pillars and long rooms is employed, often in conjunction with longwall mining of one of the two seams. Panel recoveries in longwall exceed 76%, whilst those in the long room with yield pillar average around 70%.

The Russians have carried out extensive geotechnical work investigating the magnitude and range of effects of strata disturbance in the various mining methods and have developed criteria for each method.

In the seven mines operating in the Urals region, major problems arise from the presence of aquifers above the seam, and the liability of the seams to gas outbursts. Mining is therefore limited to room and pillar with long rooms in the better conditions, or with conventional square pillars in the poorer conditions, giving panel recoveries of up to 60%.

4.3 FRANCE

Potash is currently produced by three underground mines in the Alsace region, working at depths between 400 m and 1100 m below the surface. Mining was originally by conventional room and pillar, but because of poor recovery, low productivity, and ventilation problems due to the presence of methane, the mines were gradually converted to the longwall caving method. Since 1981, all the output has been produced from longwall systems. Several longwall faces are operated in tandem, such that the width of the mining panel is approximately 750 m. Panel recoveries exceed 85%. The mines have also successfully operated longwall caving faces in seams 20 m apart vertically with the faces displaced horizontally by 25-30 metres.

4.4 SPAIN

Potash is mined in Spain in the provinces of Barcelona and Navarra. In the Navarra province, one mine is working bedded deposits at depths down to 1200 m and dipping at 13°. Mining in either one or two seams is entirely by longwall caving, though because of the nature of the immediate roof, caving has to be induced with limited use of explosives. The mining area is overlain by extensive water bearing strata, but they are sufficiently far above the potash, that the clays and marls between them form an effective seal, even for longwall caving mining. Panel recoveries exceed 80%.

In the Barcelona province, three mines are working a variety of methods which are dependent on geological conditions. In the highly folded deposits of Cardona, sub-level open stoping is used achieving panel recoveries around 80% at depths of 1100 m. In the flatter deposits of Sallent, long room and pillar mining is practised with partial backfilling being used through selective mining of the salt interburden between the two seams being mined Panel recoveries of 50% are being achieved in the potash beds at some 450 m below the surface. In similar deposits at Suria, room and pillar is again the favoured method.

4.5 WEST GERMANY

There are eight mines operating in Western Germany. Those in the flatter deposits in the southern area are working room and pillar systems with conventional square pillars and no pillar mining, and are achieving panel recoveries between 55 and 80% from the workings varying between 400 m and 1000 m depth.

In the more steeply folded deposits in the North, working at depths between 750 m and 1300 m, the sub-level open stoping system with subsequent backfill with salt tailings is the method used. Panel recoveries range from 80%-90% dependent on the working depth.

4.6 EAST GERMANY

East Germany is the third largest potash producer, working eleven underground mines. The bulk of these operate room and pillar systems, with the exception of the three mines in the south which practise a form of open stoping or large chamber mining in the thick seams. No figures are available for panel recoveries.

4.7 UNITED KINGDOM

There is one mine producing potash from a depth of 1100 metres. Because of severe variations in seam thickness in the relatively flat deposits, and of the liability of the seam to gas outbursts, the mining method, which initially was standard room and pillar, has evolved to the long room and yielding pillar system incorporating stress relief techniques.

4.8 ITALY

There are five operating underground mines in Italy, where the deposits vary from 240 m to 840 m in depth, and in attitude from flat to steeply folded. Mining methods thus range from room and pillar, to block caving and sub-level stoping. No panel recovery figures are available.

5.0 MINING METHODS SUMMARY

There are some eight basic mining methods used to mine potash around the world. Methods used outside Canada show much greater recoveries of potash, some in conditions almost as restrictive as those in Saskatchewan. Table II lists the mining methods, the recovery from the mining panels, and the estimated world production from that method.

In the study, the mining methods were evaluated on the basis of the ore recovered from a mining panel (panel recovery) rather than that recovered from the total mine (overall recovery). Since the overall recovery reflects the specific geological state and may also be derived from the use of more than one mining method. The panel recovery relates to a specific mining method and is thus more representative.

Table III (Table 5-5 of the report) lists the principal characteristics of the underground potash mines operating around the world.

6.0 ALTERNATIVE MINING METHODS

Alternative mining methods must offer benefits over present methods. The most tangible benefits sought are improved recovery, improved working conditions, improved productivity and hence reduced costs.

Evaluation of the various methods used to mine potash around the world, and of the conditions existing in the Canadian potash mines has indicated that alternatives do exist to the mining methods presently in use, subject to the necessary geotechnical investigations.

Alternatives identified for further detailed study for the short/medium and long term were:

.1 Saskatchewan - Esterhazy District

In the short/medium term

(a) Shortwall Retreat Mining - with yielding pillars
- with backfill
- with backfill and yielding pillars

(b) Longwall Retreat Mining - with backfill

In the long term, solution mining applied to the abandonned underground workings.

.2 Saskatchewan - Saskatoon District

In the short/medium term

(a) Shortwall Retreat Mining - with yielding pillars
- with backfill
- with backfill and yielding pillars

In the long term solution mining of the abandonned underground workings.

.3 New Brunswick

No alternatives are recommended since the mines are just starting or about to start, and mining techniques should be state-of-the-art until actual mining behaviour has been determined and the selected mining method properly evaluated. In the medium to long term, alternatives will be required to deal with expected changed conditions.

In addition to the above, the preliminary underground separation of salt through the use of electrostatic precipitation was considered worth investigating further.

7.0 GEOTECHNICAL PROGRAM

Before any alternative mining method is introduced into an existing mine, a thorough examination of the geotechnical factors which will affect or be affected by the behaviour of the mine and its constituent rocks will have to be undertaken. A geotechnical program for developing the criteria necessary to enable an alternative mining method to be safely and successfully introduced should include the following:

a) Characterization of the hanging wall and footwall.

b) Assessment of groundwater hydrological conditions.

c) Characterization and evaluation of the behaviour of mine when working previous methods.

d) Characterization and evaluation of backfill.

e) Determination of mine behaviour using alternative mining methods.

8.0 CONCLUSIONS

The following conclusions were reached.

1. The mining systems in the Saskatchewan potash mines could be changed from the present room and pillar methods to shortwall mining or possibly longwall mining methods incorporating backfill and/or yielding pillars.

2. Changes of mining method have been successfully completed in potash mines in USSR, France and Spain.

3. Mining recoveries in potash can be improved. Experience in the USA and Europe indicates that improvements of up to 1.7 times the Saskatchewan rates are possible with shortwall and longwall methods.

4. The use of backfill improves control of the saltback and will almost certainly have to be used in Saskatchewan, if alternative minning systems are introduced.

5. A more detailed analysis of the alternative mining methods is required to relate the characteristics of each method to the specific mine site conditions to which it is to be applied.

6. A geotechnical program of investigation is essential before any new mining method is introduced into a mine. This is essential to ensure that the interaction between site conditions and mining method requirements do not adversely affect the integrity of the mine.

7. The primary separation of potash and salt underground has potential advantages, particularly in reducing the need to hoist uneconomical waste up the shaft.

8. Alternative mining methods can be beneficial in improving mining recovery, increasing production and productivity, reducing costs and improving safety.

9. Solution mining provides an opportunity in the long term to recovery the remaining potash from a mine following cessation of conventional underground mining.

9.0 RECOMMENDATIONS

The primary objective of the study was to review the state-of-the-art of underground methods of mining potash around the world and identify potential alternatives for use in Canada.

The study has identified several potential methods, and also the need for more detailed information about these methods, and how they could be applied, particularly to the Saskatchewan mines.

We therefore make the following recommendations for the further work we consider necessary to enable a full and proper evaluation to be made of the selected alternative mining methods.

1. A more detailed examination should be made of the techniques, methods and controls used in other countries where the basic mining method has been drastically and successfully changed. We refer particularly to the Byelorussia mines in the USSR, the Alsace mines in France, the Navarra mine in Spain and the Carlsbad mines in New Mexico.

2. A detailed study should be made of the critical characteristics and operating parameters of the following alternative mining methods:

    (i) Shortwall with yield pillars

    (ii) Shortwall with backfill

    (iii) Shortwall with backfill and yielding pillars

    (iv) Longwall with backfill

(v) Longwall with caving

3. The development of a detailed geotechnical program for relating the specific conditions at mines in both the Saskatoon and Esterhazy regions, with the specific characteristics of the various alternative mining methods.

4. A feasibility study to carry out a detailed comparison of selected alternative mining methods for a selected mine in the Saskatoon region, and a selected mine in the Esterhazy region.

5. A study of the properties and behaviour of salt tailings backfill; of the various methods of placing backfill; and of the characteristics of the placed fill.

6. A study of the electrostatic precipitation system of potash beneficiation and of its potential operation in an underground environment.

7. Preliminary studies should be undertaken to assess the application of solution mining to existing conventional underground mines, with particular reference to the composition and temperature of injected and recovered fluids, potash dissolution rates in the mine, retention times in the mine, and the process modifications required to treat the brines recovered from the mine.

TABLE I

World Wide Potash Production 1982/3

Country	Production (kt K_2O)	Surface (S) or Underground (U)
USSR	8,079	U
Canada	5,379	U
E. Germany	3,434	U
W. germany	2,226	U
U.S.A.	1,639	U
France	1,601	U
Israel	946	S
Spain	702	U
U.K.	263	U
Italy	127	U
China	25	US
Chile	21	S
Others	9	S
	24,451	

TABLE II

Potash Mining Methods

Method	No. of Mines	Panel Recovery %	Estimated Production Mt K_2O/yr
Room and Pillar	56	50-80	25.0
Longwall	8	80-85	4.2
Sub-level Stoping	9	80-90	2.0
Shortwall	2	90-92	1.3
Solution	2	100*	1.2
Cut and Fill Stoping	1	80	0.7
Block Caving	1	-	0.5
Shrinkage Stoping	7	78	0.4

* Theoretical

TABLE 5-5 SUMMARY OF PRINCIPAL CHARACTERISTICS OF UNDERGROUND POTASH MINES

REF. COMPANY, MINE, LOCATION	YEAR of PRODUCTION	TOTAL RESERVES (Mt)	PRESENT PROD. CAPACITY (Mt K20/yr)	PRESENT ORE CAPACITY (Mt ore/yr)	AVERAGE GRADE (% K20)	DEPTH (m)	GRADIENT (degrees)	OVERALL RECOVERY (%)	MINING METHOD	TOTAL EMPLOYEES	REMARKS
CANADA											
01 PCA - PENOBSQUIS, NB	1984	-	0.7	2.3	25	460-760	25-45	55-60	CUT & FILL	245	-
02 DENISON - SALTSPRINGS, NB	1985	230	1.0	3.6	28	835	12-20	60-65	R & P LONG, BACKFILL	-	-
03 BP - MILLSTREAM, NB	(1988)	256	-	-	22	840-1200	5-70	23	R & P LONG, BACKFILL	441	-
04 PCS - ROCANVILLE, SASK	1971	-	0.78	3.0	27	960	0.2	33	R & P LONG	-	-
05 IMC - K1 & K2, SASK	1962/67	-	2.32	9.3	25	955	0.2	35	R & P LONG	-	-
06 PCS - CORY, SASK	1969	-	0.83	3.2	18-26	1012	0.2	38	R & P LONG	-	-
07 PCS - LANIGAN, SASK	1968	-	0.60	3.0	20-24.5	1006	0.2	-	CHREVRON	-	-
08 PCS - ALLAN, SASK	1968	-	0.97	3.6	27.3	1036	0.2	-	R & P LONG	-	-
09 COMINCO - VANSCOY, SASK	1969	112	0.50	3.6	25-30	1076	0.2	39	R & P CHEVRON	-	-
10 CCP - COLONSAY, SASK	1969	-	0.82	3.1	22-32	1021	0.2	35	R & P LONG	-	-
11 PCA - SASKATOON, SASK	1958	-	0.42	1.6	27	1016	0.2	-	R & P CHEVRON	-	-
12 PPG - KALIUM, SASK	1964	-	0.85	-	-	1730	-	-	R & P LONG SOLUTION	-	-
UNITED STATES											
01 KERR MCGEE - HOBBS, NM	1966	63.5	0.2	3.3	13-18	500	1.2	55	R&P CHEVRON	398	
02 MISSISSIPPI - CARLSBAD,NM	1931	290	0.2	2.6	14-33	260-500	1.7	-	SHORTWALL	406	on care and mtce
03 AMAX - CARLSBAD, NM	1953	-	0.5	4.1	11-19	220-340	1.1	-	SHORTWALL	-	
04 PCA - CARLSBAD, NM	1934	10	0.5	3.1	12-23	305	0.8	70	R&P, DEPILLARING	396	
05 IMC - CARLSBAD, NM	1940	-	0.3	-	10-14	215-270	1.0	-	R & P	-	
06 NATIONAL POTASH - LEA, NM	1957	-	0.2	-	14	490-550	1.0	-	R & P	-	
07 DUVAL - NASH DRAW, NM	1964	37.7	0.1	-	8-16	274-328	1.1	-	R & P	-	
08 TEXAS GULF - CANE CREEK, UT	1965 (conv) 1970(sol)	-	0.2	-	27	920	8.8	100	SOLUTION	100	
SPAIN											
01 MPS - SURIA, CATALONIA	1926	-	0.3	1.8	16.5	550-680	60-70	-	ROOM & PILLAR	-	
02 UERT - CARDONA, CATALONIA	1930	62.5	0.25	2.5	11-12	1100	20-60	66	SUB-LEVEL OPEN STOPING	680	
03 UERT - LLOBREGAT, CATALONIA	1934/1948	16.0	0.4	1.7	12-20 22.5	45	5-10	50	LONG ROOM & PILLAR CHEVRON & BACKFILL	-	
04 PDN - ESPARZA, NAVARRA	1963	-	0.325	2.8	13	200-1500	13	70	LONGWALL CAVING (ADVANCING)	-	
UNITED KINGDOM											
01 CPL - BOULBY, CLEVELAND	1973	-	0.48	1.7	25-30	1066	1 in 10	25	ROOM & PILLAR (D&B)	-	
ITALY											
01 ISPEA - SAN CATALDO/PALO, SICILY	1960 (sc) 1974 (p)	-	0.45-0.50	-	12 10-17	200	0-45	45	R & P	600	
02 ISPEA - RACALMOLTO, SICILY	1973	-	0.65	-	11	840	25	40	R & P (SUBLEVEL)	-	
03 ISPEA - PASQUASIA, SICILY	1964	-	1.0	-	14.5	825 757 310	25-30	-	R & P	-	
04 ISPEA - CORVILLO, SICILY	1967	-	0.2	-	15-17	-	-	-	BLOCK CAVING	-	
05 ISPEA - MILENA, SICILY	U.D.	-	0.5	-	-	1250	-	-	R & P	-	
06 ISPEA - REALMONTE, SICILY	1977	-	0	-	15-17	150	60-65	-	- STOPING	-	
FRANCE **MINES DE POTASSE d'ALSACE (MDPA)**											
01 AMELIE	1910	-	|	12.9	19	420-1100	up to 35	-	LONGWALL	-	
02 THEODORE	-1914	-	1.8	7.7	19	420-1100	up to 35	-	LONGWALL	-	
03 MARIE-LOUISE	-1914	-	|	14.5	19	420-1100	up to 35	-	LONGWALL	-	
GERMAN FEDERAL REPUBLIC **KALI UND SALZ AG**											
01 BERGMANSSEGEN - HUGO	-	-	0.21	1.81	11.5	350-1200	40-90	85-90	OPEN SUBLEVEL STOPING	-	
02 SALZDETFURTH	1900	-	0.25	1.96	12.5	770-900	40-90	85.90	"	-	
03 SIEGFRIED - GIESEN	1906	-	0.12	1.13	10.8	1050	40-90	85-90	"	-	
04 SIGMUNDSHALL	-	-	0.30	1.78	16.9	400-1040	40-90	85-90	"	-	
05 NIEDERSACHSEN - RIEDEL	1910	-	0.15	1.12	14.0	750-1320	40-90	85-90	"	-	
06 WINTERSHALL	1903	-	0.44	6.1	11.0	540	2-3	70	R & P	-	
07 HATTORF	1910	-	0.37	4.5	11.1	700-1060	2-3	55-65	"	-	
08 NEUHOF - ELLERS	-	-	0.31	3.2	12.0	400-600	2-3	55-65	"	-	
GERMAN DEMOCRATIC REPUBLIC **KALIBETRIEB WERRA**											
01 UNTERBRIEZBACH	-	-	|	-	-	-	-	50	R & P	-	
02 MERKERS	-	-	0.72	-	-	-	-	50	R & P	-	
03 DORNDORF	-	-	|	-	-	-	-	50	R & P	-	
KALIBETRIEB SUD HARZ											
04 ROSSLEBEN	1905	-	0.32	-	-	700	-	50	R & P	-	
05 SONDERSHAUSEN	-	-	-	-	-	-	-	50	R & P	-	
06 SOLLSTEDT	1905	-	-	-	-	-	-	50	R & P	-	
07 BLEICHRODE	1902	-	-	-	-	-	-	50	R & P	-	
08 VOLKENRODA	1909	-	-	-	-	-	-	50	R & P	-	
09 BISCHOFFERODE	1915	-	0.510	-	-	-	-	50	R & P	-	
KALI-UND STEIN SALZBETRIEB SAALE											
10 TEUTSCHENTAL	1907	-	-	-	-	-	-	50	R & P	-	
KALIBETRIEB ZIELITZ											
11 ZIELITZ	1973		0.9	5.3	17	800	18-25	50	R & P	-	
RUSSIA **URALS**											
01 BEREZNIKI NOS.1-4	1931	|	5.2-5.3	12.3-13.1	21	300-500	-	-	DOME & PILLAR	-	
02 SOLIKANSK NOS. 1&2	1931	15900	1.4	3.5	14-15	200-500	-	-	ROOM & PILLAR	-	
03 NOVO SOLIKANSK	1983	|	1.9-2.0	4.5-5.0	14-15	200-500	-	-	ROOM & PILLAR	-	
BYELORUSSIA											
04 SOLIGORSK NOS. 1-4	1963 (no.1) 1978 (no.4)	2800	5.0-5.2	11.8-12.2	13.4-17.7	420-650	5.0	80-85 OVERALL 43-45 R&P 70-75 LONGWALL	R&P, LONGWALL	16000 SURF + U/G	
UKRAINE											
05 KALUSH - STEPNIK AREA	1923 (old) 1967 (new)	2900	0.4	0.9	8-12	100-300	19-27	90.5	R & P SHRINKAGE STOPING	-	

TABLE 5-5

SUMMARY OF PRINCIPAL CHARACTERISTICS OF UNDERGROUND POTASH MINES

RESUME DE LA DIRECTION

(Version française)

1.0 INTRODUCTION

Ce rapport a ête préparé par Montreal Engineering Company Limited, avec l'aide de Minco Consultants (Aspects Géologiques) et Golder Associates Western (Aspect Géotechniques) par suite de la demande de Canmet. Son but est d'identifier des méthodes d'exploitation de la potasse souterraine, autres que celles qui sont actuellement utilisées au Canada, en accordant une importance particulière aux aspects qui permettraient une amélioration des quantités et (ou) une diminution des frais d'exploitation.

En ce qui concerne les taux d'exploitation et le rendement, l'industrie de la potasse de la province de Saskatchewan a les pourcentages les plus bas du monde. Ceci signifie que pour une superficie souterraine donnée, les méthodes d'exploitation utilisées ne permettent pas de récupérer plus du tiers du minerai disponible. D'autres méthodes sont utilisées qui permettent d'extraire jusqu'au trois quarts du minerai. Par conséquent, il est tout particulièrement important, pour l'industrie de la potasse canadienne, de passer en revue ces diverses méthodes d'exploitation et d'évaluer les possibilités d'application aux conditions d'exploitation canadienne.

L'augmentation du pourcentage de minerai exploité pour une surface donnée a un effet salutaire appréciable, à la fois pour les coûts opératoires et ceux d'installation, de même que pour l'exploitation efficace de la mine. Les chantiers se concentrent dans un espace plus petit ce qui réduit les frais de transport, d'aérage et autres service nécessaires.

les communications et le contrôle sont plus aisés et les travaux d'aménagement moindres, et les machines peuvent alors être utilisées avec un rendement supérieur par panneau.

2.0 METHODES D'ETUDE

La potasse est exploitée selon des méthodes souterraines dans une dizaine de pays du monde. Ceci comprend, outre le Canada qui est le second producteur (tableau I), les Etats-Unis, l'U.R.S.S., l'Allemagne de l'ouest, l'Allemagne de l'est, la France, l'Espagne, l'Italie, le Royaume-Uni et la Chine. Trois méthodes ont été employées pour recueillir l'information sur une telle étendue:

1) des visites de mines au Canada et aux Etats-Unis,
2) la circulation d'un questionnaire dans 43 mines du monde,
3) la recherche de documentation.

Une grosse partie des informations utilisées dans ce rapport provient des visites de mines, d'une étude de la documentation et des données sur place. Les réponses au questionnaire n'ont atteint que 14% et ceci reflète peut-être le caractère concurrentiel de cette industrie.

3.0 METHODES D'EXPLOITATION AU CANADA

Au Canada, l'exploitation de la potasse s'effectue dans les provinces de Saskatchewan et du Nouveau Brunswick.

3.1 LE NOUVEAU BRUNSWICK

Les mines de potasse du Nouveau Brunswick sont les plus récentes. La première mine (PCA) a commencé à produire en 1984, la seconde (Denison) sera mise en service en 1985 et la troisième (BP) vers la fin des années 80.

Les caractéristiques des gisements du Nouveau Brunswick sont tout-à-fait différentes de celles du Saskatchewan. Les couches de potasse ont un pendage plus marqué, sont d'épaisseur variée, fortement plissées ou forment des structures en dôme. Dans la province de Saskatchewan, les couches sont régulières, d'épaisseur égale et presque planes.

Les méthodes d'exploitation employées, ou qui sont supposées être employées, sont en outre dictées par l'exigence du gouvernement provincial qu'aucun résidu salifère ne demeure en surface.

La seule mine en service (PCA) a optée pour l'exploitation par chantiers individuels et remblayage dans les zones inclinées. Elle compte obtenir une production d'à peu près 80%. Les deux autres mines ont choisi l'exploitation par chambres et piliers avec longues chambres et remblayage, ceci pour parvenir à une production de 40% à 60% par panneau.

En général, l'épaisseur de la couche de sel située immédiatement au-dessus des chantiers d'exploitation est variable allant d'un minimum de 100 m. à PCA, de 10 m. à 100 m. à Denison et de 20 m. à 50 m. à BP. L'épaisseur minimum admise est de 10 m. à Denison et de 20 m. à BP.

3.2 LE SASKATCHEWAN

Dans la province de Saskatchewan l'exploitation de la potasse selon des méthodes conventionnelles se fait dans deux régions: Esterhazy et Saskatoon.

Les caractéristiques du gisement d'Esterhazy sont les plus favorables car la couche de sel qui recouvre les 2,4 m. de potasse exploitée est d'environ 30 m. d'épaisseur. Aux environs de 960 m. de profondeur, l'exploitation se fait par longues chambres et piliers - évolution de la chambre standard à piliers carrés - ceci dans le but de résoudre les problèmes de contrôle du toit et de rendement bas. La production par panneau est d'environ 55%. L'exploitation s'effectue sans défruitement des piliers. La production totale des deux mines d'Esterhazy est en moyenne de 35%.

La profondeur des six mines de la région de Saskatoon est de 1000 m. à 1150 m. Elles ont débuté avec l'exploitation par chambres et piliers. Cepandant, la minceur (8 à 14 m.) de la couche de sel située immédiatement au-dessus des chantiers d'exploitation, ainsi que la présence de bancs d'argile dans la couche adjacente, ont posé de sérieux problèmes de toit et de sol. Il a fallu remplacer la méthode initiale par l'exploitation actuelle de chambres et piliers avec, soit des longues chambres, soit des agencements en chevron qui incorporent des techniques de stabilisation. La production totale se situe entre 35% et 38%, alors que celle par panneau varie de 50% à 60%. Avec la méthode d'exploitation initiale, la production totale tournait autour de 25%.

Dans la province de Saskatchewan, l'exploitation est gouvernée tout particulièrement par la profondeur de la couche de potasse et le poids des strates supérieures ainsi que par la nécessité d'éviter la rupture de la couche aquifère du Dawson Bay située immédiatement au-dessus de la couche de sel. Ces deux faits doivent être pris en considération lors de l'étude d'autres méthodes d'exploitation.

3.3 REGINA

Les gisements de potasse de la province de Saskatchewan deviennent plus profonds en direction du sud-ouest. De ce fait, dans la région de Regina, ils sont à une profondeur de 1500 m. et les méthodes conventionnelles d'exploitation souterraine ne peuvent pas être utilisées. La seule mine en service dans cette région exploite la potasse par dissolution au moyen de puits d'extraction.

4.0 METHODES D'EXPLOITATION DANS LE MONDE

Comme il faut s'y attendre, les méthodes utilisées ailleurs dans le monde varient en fonction de la nature et de l'épaisseur du gisement.

4.1 AUX ETATS-UNIS

Dans l'état du Nouveau Mexique, les sédiments stratifiés relativement plats et réguliers sont à une profondeur variant de 260 m. à 550 m. L'exploitation est effectuée par cinq mines. L'épaisseur de la couche de sel supérieure est énorme dépassant dans chacun des cas 200 m. Dés le début, l'exploitation s'est développée par chambres standards et piliers mais de nombreuses variantes sont aussi utilisées. Dans une des mines, l'exploitation par chambres et piliers défruités permet une récupération par panneau de 90% et totale de 70%. L'exploitation par chambres et piliers, soit avec longues chambres, soit avec agencement en chevron, permet une production totale de 55% et par panneau de 75%.

L'exploitation par tailles courtes utilisant des piliers minces et coulissants est d'un intérêt tout particulier. Ce procédé est employé avec succés et permet d'extraire 92% du panneau pour des bancs de 1,2 m. à 1,5 m. d'épaisseur, tout en maintenant le contrôle du toit. Cette méthode convient parfaitement et est d'un intérêt considérable pour les mines de potasse canadiennes.

Dans l'état de Utah, une mine seulement exploite la potasse. Initialement, l'exploitation souterraine s'est faite de façon conventionnelle par chambres et piliers. Cependant, l'environnement géologique difficile, ainsi que le pan incliné, ont obligé à passer à une exploitation par dissolution. Des puits ont été forés de la surface aux chantiers souterrains et la potasse est maintenant exploitée avec succés et de façon économique.

Dans l'état de Wyoming, la mine de trona visitée se situe à une profondeur de 975 m. L'exploitation se fait à la fois par longues tailles et chambres conventionnelles et piliers. La production par panneau est de 81% et de 36% respectivement.

4.2 EN U.R.S.S.

En tant que premier producteur de potasse du monde, l'U.R.S.S. a des mines dans trois régions et leurs caractéristiques sont différentes. La production la plus petite provient de l'Ukraine où huit petites mines produisent 400 000 tonnes par an. L'exploitation de couches en dressant se fait par chambres et piliers et par chambres-magasins (remblayées). La production par panneau atteint en moyenne 78%.

Dans la région de Biélorussie, les quatre mines ont tout d'abord été exploitées par chambres conventionnelles et piliers. Les couches sont relativement plates et à environ 350 à 620 m. de profondeur. Cependant, les productions totale et par panneau étaient basses et le contrôle du toit posait des problèmes. Des recherches géotechniques approfondies et des essais ont amené à l'exploitation par longues tailles foudroyées avec extraction en une tranche unique ou deux.

Dans les régions où le foudroyage n'est pas possible à cause des couches aquifères, l'exploitation s'effectue par chambres et piliers, avec piliers coulissants et longues chambres, souvent en conjonction à l'exploitation par longues tailles d'une ou de deux couches. L'exploitation par longues tailles permet une récupération par panneau dépassant 76% tandis que celle par longues chambres et piliers coulissants tourne autour de 70%.

Les Russes ont entrepris des travaux géotechniques approfondis. Ils ont examiné l'envergure et la portée des effets provoqués par la perturbation des couches géologiques pour chacune des diverses méthodes d'exploitation et ont développé des critères pour chacune d'elles.

Dans les sept mines en service dans la région de l'Oural, des problèmes majeurs se posent dus à la présence des couches aquifères au-dessus de celle de potasse. L'exploitation est, par conséquent, limitée aux chambres et piliers avec des longues chambres lorsque l'environnement géologique est le plus favorable, ou avec des piliers carrés conventionnels dans le cas inverse, ce qui permet une production par panneau qui atteint 60%.

4.3 EN FRANCE

En Alsace, la potasse est exploitée dans trois mines souterraines. L'exploitation se situe entre 400 m. et 1100 m. de profondeur. A l'origine, l'exploitation s'est effectuée par chambres et piliers, mais à cause d'une production peu élevée et des problèmes d'aérage dus à la présence de méthane, les mines se sont progressivement converties à l'exploitation par longues tailles foudroyées. Depuis 1981, la totalité de la production dépend des méthodes de longues tailles. Plusieurs grands fronts alignés sont travaillés en tandem, de sorte que la largeur du panneau d'extraction est d'environ 750 m. La production par panneau dépasse 85%. Les mines ont aussi réussi à exploiter des faces de longues tailles foudroyées en couches séparées verticalement de 20 m. et d'un décalage horizontal de 25 - 30 mètres.

4.4 EN ESPAGNE

Deux provinces espagnoles sont productrices de potasse: la Navarre et Barcelone. En Navarre, une des mines exploite des sédiments stratifiés à une profondeur de 1200 m. avec un pendage de 13°. L'exploitation s'effectue uniquement par longues tailles foudroyées d'une ou de deux couches. Cependant, à cause de la nature du toit adjacent, le foudroyage doit être provoqué par un emploi d'explosifs limité. La zone exploitée est souvent recouverte par de vastes strates chargées d'eau. Mais celles-ci sont bien au-dessus de la potasse et les terrains argileux et marneux qui s'y intercalent, forment une couche étanche efficace même dans le cas d'exploitation par longues tailles foudroyées. La production par panneau dépasse 80%.

Dans la province de Barcelone, l'exploitation des trois mines se fait selon des méthodes variées qui dépendent de l'environnement géologique. Dans les environs de Cardona où les gisements sont fortement plissés, l'exploitation en sous-étages permet une production d'environ 80% à une profondeur de 1100 m. Dans les gisements presque horizontaux de Sallent, l'exploitation s'effectue par longues chambres et piliers avec remblayage partiel utilisant les déchets salifères situés entre les deux couches de potasse. Celles-ci sont à une profondeur de 450 m. et la production par panneau atteint 50%. Pour les gisements à peu près identiques de Suria, l'exploitation par chambres et piliers est, là-aussi préférée.

4.5 EN ALLEMAGNE DE L'OUEST

Huit mines sont en service en Allemagne de l'ouest. Dans la région du sud où les gisements sont presque horizontaux, l'exploitation s'effectue par chambres et piliers avec des piliers carrés conventionnels, sans défruitement des piliers. La production par panneau atteint entre 55% et 80% pour des chantiers d'une profondeur variant de 400 m. à 1000 m.

Au nord où les gisements sont plissés et plus inclinés, l'exploitation s'effectue à une profondeur de 750 m. à 1300 m. en sous-étages suivi d'un remblayage utilisant les résidus salifères. La production par panneau va de 80% à 90% selon la profondeur du chantier.

4.6 EN ALLEMAGNE DE L'EST

L'Allemagne de l'est est le troisième producteur mondial. Elle exploite onze mines souterraines. La grosse partie de celles-ci fonctionnent selon les méthodes de chambres et piliers excepté trois mines du sud qui utilisent un type d'abattage en gradins ou l'exploitation par grande chambre lorsque les couches sont épaisses. Les chiffres de production par panneau ne sont pas connus.

4.7 AU ROYAUME-UNI

Une mine seulement produit de la potasse d'une profondeur de 1100 m. La méthode d'exploitation initiale consistait de chambres standards et piliers. Cependant, l'épaisseur de la couche dans les gisements relativement horizontaux variant énormément et le danger d'explosion de gaz dans la couche, ont amené à l'utilisation de la longue chambre et piliers coulissants incorporant des procédés de stabilisation.

4.8 EN ITALIE

En Italie, cinq mines souterraines sont en service. Les gisements sont à une profondeur qui varie de 240 m. à 840 m. et la forme va de l'horizontale au fortement plissé. Ainsi, les méthodes d'exploitation vont de la chambre et piliers, au foudroyage en masse et à l'exploitation en sous-étages. Les chiffres de production par panneau ne sont pas connus.

5.0 RESUME DES METHODES D'EXPLOITATION

Dans le monde entier, huit méthodes d'exploitation de base sont employées pour l'extraction de la potasse. Les méthodes utilisées ailleurs qu'au Canada permettent une récupération de potasse supérieure, ceci même lorsque l'environnement géologique est presque aussi contraignant que celui de la province de Saskatchewan. Le tableau II donne la liste des méthodes d'exploitation, la production par panneau d'extraction et une estimation de la production mondiale obtenue par chacune de ces méthodes.

Dans cette étude, les méthodes d'exploitation ont été évaluées à partir du minerai récupéré d'un panneau d'extraction (production par panneau) plutôt que celui récupéré par l'ensemble de la mine (production totale). Ceci parce que la production totale reflète la situation géologique particulière et peut aussi être dérivée de l'emploi de plus d'une méthode d'exploitation. La production par panneau est en rapport à la méthode d'exploitation particulière et est ainsi plus représentative.

Le tableau III donne la liste des caractéristiques principales des mines de potasse souterraines en service dans le monde entier.

6.0 METHODES D'EXPLOITATION SECONDES

Toute méthode d'exploitation seconde doit avoir des avantages que la méthode utilisée ne possède pas. Les avantages matériels les plus recherchés sont: une récupération accrue, une amélioration des conditions de travail, une augmentation de la productivité et, en conséquence, une réduction des coûts.

L'évaluation des diverses méthodes d'exploitation de la potasse dans le monde et des conditions actuelles des mines de potasse canadiennes, démontre qu'il existe des méthodes autres que celles utilisées en ce moment et que ces méthodes secondes dépendent des recherches géotechniques nécessaires.

Les méthodes secondes qui ont été définies à court, moyen et long termes, nécessitent une analyse plus détaillées et sont les suivantes:

0.1 Le Saskatchewan - la région d'Esterhazy

A court ou moyen terme:

a) l'exploitation par courte taille rétrograde
    - avec piliers coulissants
    - avec remblai
    - avec remblai et piliers coulissants

b) l'exploitation par longue taille rétrograde avec remblai

A long terme: l'exploitation par dissolution pour les chantiers souterrains abandonnés.

0.2 Le Saskatchewan - la région de Saskatoon

A court ou moyen terme:

a) l'exploitation par courte taille rétrograde
   - avec piliers coulissants
   - avec remblai
   - avec remblai et piliers coulissants

A long terme: l'exploitation par dissolution pour les chantiers souterrains abandonnés.

0.3 Le Nouveau Brunswick

Aucune autre méthode n'a été recommandée puisque les mines viennent tout juste d'être ouvertes où vont l'être et les techniques d'exploitation devraient atteindre la perfection. Seul, le comportement réel de la mine permettra de savoir si la méthode d'exploitation choisie a été correctement évaluée. A moyen et long termes, d'autres méthodes seront nécessaires pour faire face aux changements inévitables de l'environnement.

Outre ceci, la séparation électrostatique préliminaire du sel vaut la peine d'être examiné plus à fond.

7.0 PROGRAMME GEOTECHNIQUE

Avant d'introduire une seconde méthode d'exploitation dans une mine, une étude complète devra être entreprise portant sur les facteurs géotechniques qui affecteront ou seront affectés par le comportement de la mine et de ses roches constituantes. Pour être mise en oeuvre en toute sûreté et avec succés, tout programme géotechnique développant les critères nécessaires permettants une seconde méthode d'exploitation devra comprendre les points suivants:

a) la caractérisation du toit et du sol.

b) l'évaluation des conditions hydrologiques de l'eau souterraine.

c) la caractérisation et l'évaluation du comportement de la mine au cours de l'emploi des méthodes précédentes.

d) la caractérisation et l'évaluation du remblai.

e) la détermination du comportement de la mine lors de l'utilisation d'autres méthodes d'exploitation.

8.0 CONCLUSIONS

Les conclusions sont les suivantes:

1) les méthodes actuelles d'exploitation par chambres et piliers des mines de potasse de Saskatchewan devraient être remplacées par celles par tailles courtes ou, peut-être, par les méthodes d'extraction par longues tailles incorporant un remblayage et (ou) des piliers coulissants.

2) Les mines de potasse de l'U.R.S.S., de la France et de l'Espagne ont réussi à changer leurs méthodes d'exploitation.

3) La production des mines de potasse peut être améliorée. L'expérience des Etats-Unis et de l'Europe démontre qu'il est possible d'augmenter les quantités produites par les mines de Saskatchewan jusqu'à 1,7 fois en utilisant les méthodes de courtes et de longues tailles.

4) L'utilisation du remblayage permet un meilleur contrôle de la couche de sel supérieure et devra surêment être employé dans le Saskatchewan si d'autres méthodes d'exploitation sont adoptées.

5) Une analyse plus détaillée des méthodes d'exploitation secondes est nécessaire. Elle devra établir un rapport entre les caractéristiques de chacune des méthodes secondes et les conditions spécifiques de chaque mine considérée.

6) Pour chaque mine, un programme de recherches géotechniques doit précéder l'introduction de toute méthode seconde d'exploitation. Ceci est indispensable pour assurer que l'interaction de l'environnement géologique de la mine et des exigences de la méthode d'exploitation n'ait pas un effet adverse sur l'intégrité de la mine.

7) La séparation préliminaire souterraine de la potasse et du sel a des avantages virtuels, en particulier celui de diminuer la quantité de déchets qui est remontée en surface.

8) Les méthodes d'exploitation secondes peuvent être salutaires. Elles permettront d'améliorer la récupération de potasse des mines, d'accroître la production et la productivité, de réduire les coûts et d'améliorer la sécurité.

9) A long terme, l'exploitation par dissolution offre le moyen de récupérer la potasse qui subsiste lorsque l'exploitation souterraine conventionnelle est achevée.

9.0 RECOMMANDATIONS

L'objectif essentiel de cette étude était de passer en revue les méthodes les plus perfectionnées d'exploitation souterraine de la potasse dans le monde entier et de déterminer celles qui pourraient être utilisées au Canada.

Plusieurs méthodes ont été identifiées, ainsi que la nécessité d'obtenir des informations plus détaillées sur ces méthodes et la façon dont elles pourraient être appliquées tout particulièrement aux mines de Saskatchewan.

Par conséquent, nous considérons que les recommandations suivantes doivent faire l'objet d'un examen plus approfondi pour parvenir à une évaluation complète et correcte des méthodes d'exploitation secondes choisies:

1. Une étude plus détaillée portant sur les techniques, les méthodes et les procédés de contrôle employés dans les autres pays qui ont réussi à changer leur méthode d'exploitation de base, en particulier les mines de Biélorussie en U.R.S.S., celles d'Alsace en France, de Navarre en Espagne et de Carlsbad au Nouveau Mexique.
2. Une étude détaillée portant sur les caractéristiques critiques et les paramètres d'exploitation des méthodes d'exploitation secondes suivantes:

   I - tailles courtes et piliers coulissants
   II - tailles courtes et remblayage

III - tailles courtes avec remblayage et piliers coulissants
IV - longues tailles avec remblayage
V - longues tailles foudroyées

3. Le développement d'un programme géotechnique détaillé en rapport aux conditions spécifiques des mines des régions de Saskatoon et Esterhazy ainsi que les caractéristiques spécifiques des diverses méthodes d'exploitation secondes.

4. Un examen portant sur les possibilités de réalisation pour comparer de façon détaillée les méthodes d'exploitation secondes choisies pour une mine donnée dans la région d'Esterhazy.

5. Une étude des propriétés et du comportement du remblayage par résidus salifères et des diverses méthodes de disposer le remblai, ainsi que de ses caractéristiques.

6. Un examen du système de séparation électrostatique de la potasse et de ses possibilités d'exploitation sous-sol.

7. Des études préliminaires devraient être entreprises pour évaluer l'application de l'exploitation par dissolution aux mines souterraines conventionnelles, en accordant une attention particulière à la composition et à la température des liquides injectés et recueillis, aux taux de dissolution de la potasse, à la durée de rétention des liquides et au processus de transformation nécessaire pour traiter les liquides dans chaque mine.

TABLEAU I

Production Mondiale de la Potasse 1982-83

Pays	Production (kilo-tonne K_2O)	En surface (S) ou souterraine (U)
U.R.S.S.	8,079	U
Canada	5,379	U
Allemagne de l'est	3,434	U
Allemagne de l'ouest	2,226	U
Etats-Unis	1,639	U
France	1,601	U
Israël	946	S
Espagne	702	U
Royaume-Uni	263	U
Italie	127	U
Chine	25	US
Chili	21	S
Autres	9	S
	24,451	

TABLEAU II

METHODES D'EXPLOITATION DE LA POTASSE

Méthode	Nombre de mines	Production par panneau %	Estimation de la production Million de tonnes K_2O par an
Exploitation par chambres et piliers	56	50-80	25,0
Taille à long front aligné	8	80-85	4,2
Exploitation en sous-étages	9	80-90	2,0
Taille courte	2	90-92	1,3
Exploitation par dissolution	2	100*	1,2
Exploitation par chantiers individuels et remblayage	1	80	0,7
Exploitation par foudroyage en masse	1	-	0,5
Exploitation par chambres-magasins	7	78	0,4

* Théorique

TABLE 5-5 SUMMARY OF PRINCIPAL CHARACTERISTICS OF UNDERGROUND POTASH MINES

REF. COMPANY, MINE, LOCATION	YEAR of PRODUCTION	TOTAL RESERVES (Mt)	PRESENT PROD. CAPACITY (Mt K20/yr)	PRESENT ORE CAPACITY (Mt ore/yr)	AVERAGE GRADE (% K20)	DEPTH (m)	GRADIENT (degrees)	OVERALL RECOVERY (%)	MINING METHOD	TOTAL EMPLOYEES	REMARKS
CANADA											
01 PCA - PENOBSQUIS, NB	1984	-	0.7	2.3	25	460-760	25-45	55-60	CUT & FILL	245	-
02 DENISON - SALTSPRINGS, NB	1985	230	1.0	3.6	28	835	12-20	60-65	R & P LONG, BACKFILL	-	-
03 BP - MILLSTREAM, NB	(1988)	256	-	-	22	840-1200	5-70	23	R & P LONG, BACKFILL	441	-
04 PCS - ROCANVILLE, SASK	1971	-	0.78	3.0	27	960	0.2	33	R & P LONG	-	-
05 IMC - K1 & K2, SASK	1962/67	-	2.32	9.3	25	955	0.2	35	R & P LONG	-	-
06 PCS - CORY, SASK	1969	-	0.83	3.2	18-26	1012	0.2	38	R & P LONG CHREVRON	-	-
07 PCS - LANIGAN, SASK	1968	-	0.60	3.0	20-24.5	1006	0.2	-	R & P LONG	-	-
08 PCS - ALLAN, SASK	1968	-	0.97	3.6	27.3	1036	0.2	-	R & P CHEVRON	-	-
09 COMINCO - VANSCOY, SASK	1969	112	0.50	3.6	25-30	1076	0.2	39	R & P LONG	-	-
10 CCP - COLONSAY, SASK	1969	-	0.82	3.1	22-32	1021	0.2	35	R & P CHEVRON	-	-
11 PCA - SASKATOON, SASK	1958	-	0.42	1.6	27	1016	0.2	-	R & P LONG	-	-
12 PPG - KALIUM, SASK	1964	-	0.85	-	-	1730	-	-	SOLUTION	-	-
UNITED STATES											
01 KERR MCGEE - HOBBS, NM	1966	63.5	0.2	3.3	13-18	500	1.2	55	R&P CHEVRON	398	
02 MISSISSIPPI - CARLSBAD,NM	1931	290	0.2	2.6	14-33	260-500	1.7	-	SHORTWALL	406	on care and mtce
03 AMAX - CARLSBAD, NM	1953	-	0.5	4.1	11-19	220-340	1.1	-	SHORTWALL	-	
04 PCA - CARLSBAD, NM	1934	10	0.5	3.1	12-23	305	0.8	70	R&P, DEPILLARING	396	
05 IMC - CARLSBAD, NM	1940	-	0.3	-	10-14	215-270	1.0	-	R & P	-	
06 NATIONAL POTASH - LEA, NM	1957	-	0.2	-	14	490-550	1.0	-	R & P	-	
07 DUVAL - NASH DRAW, NM	1964	37.7	0.1	-	8-16	274-328	1.1	-	R & P	-	
08 TEXAS GULF - CANE CREEK, UT	1965 (conv) 1970(sol)	-	0.2	-	27	920	8.8	100	SOLUTION	100	
SPAIN											
01 MPS - SURIA, CATALONIA	1926	-	0.3	1.8	16.5	550-680	60-70	-	ROOM & PILLAR	-	
02 UERT - CARDONA, CATALONIA	1930	62.5	0.25	2.5	11-12 12-20	1100	20-60	66	SUB-LEVEL OPEN STOPING	680	
03 UERT - LLOBREGAT, CATALONIA	1934/1948	16.0	0.4	1.7	22.5	45	5-10	50	LONG ROOM & PILLAR CHEVRON & BACKFILL	-	
04 PDN - ESPARZA, NAVARRA	1963	-	0.325	2.8	13	200-1500	13	70	LONGWALL CAVING (ADVANCING)	-	
UNITED KINGDOM											
01 CPL - BOULBY, CLEVELAND	1973	-	0.48	1.7	25-30	1066	1 in 10	25	ROOM & PILLAR (D&B)	-	
ITALY											
01 ISPEA - SAN CATALDO/PALO, SICILY	1960 (sc) 1974 (p)	-	0.45-0.50	-	12 10-17	200	0-45	45	R & P	600	
02 ISPEA - RACALMOLTO, SICILY	1973	-	0.65	-	11	840	25	40	R & P (SUBLEVEL)	-	
03 ISPEA - PASQUASIA, SICILY	1964	-	1.0	-	14.5	825 757 310	25-30	-	R & P	-	
04 ISPEA - CORVILLO, SICILY	1967	-	0.2	-	15-17	-	-	-	BLOCK CAVING	-	
05 ISPEA - MILENA, SICILY	U.D.	-	0.5	-	-	1250	-	-	R & P	-	
06 ISPEA - REALMONTE, SICILY	1977	-	0	-	15-17	150	60-65	-	- STOPING	-	
FRANCE **MINES DE POTASSE d'ALSACE (MDPA)**											
01 AMELIE	1910	-	1.8	12.9	19	420-1100	up to 35	-	LONGWALL	-	
02 THEODORE	-1914	-		7.7	19	420-1100	up to 35	-	LONGWALL	-	
03 MARIE-LOUISE	-1914	-		14.5	19	420-1100	up to 35	-	LONGWALL	-	
GERMAN FEDERAL REPUBLIC **KALI UND SALZ AG**											
01 BERGMANSSEGEN - HUGO	-	-	0.21	1.81	11.5	350-1200	40-90	85-90	OPEN SUBLEVEL STOPING	-	
02 SALZDETFURTH	1900	-	0.25	1.96	12.5	770-900	40-90	85.90	"	-	
03 SIEGFRIED - GIESEN	1906	-	0.12	1.13	10.8	1050	40-90	85-90	"	-	
04 SIGMUNDSHALL	-	-	0.30	1.78	16.9	400-1040	40-90	85-90	"	-	
05 NIEDERSACHSEN - RIEDEL	1910	-	0.15	1.12	14.0	750-1320	40-90	85-90	"	-	
06 WINTERSHALL	1903	-	0.44	6.1	11.0	540	2-3	70	R & P	-	
07 HATTORF	1910	-	0.37	4.5	11.1	700-1060	2-3	55-65	"	-	
08 NEUHOF - ELLERS	-	-	0.31	3.2	12.0	400-600	2-3	55-65	"	-	
GERMAN DEMOCRATIC REPUBLIC **KALIBETRIEB WERRA**											
01 UNTERBRIEZBACH	-	-	0.72	-	-	-	-	50	R & P	-	
02 MERKERS	-	-		-	-	-	-	50	R & P	-	
03 DORNDORF	-	-		-	-	-	-	50	R & P	-	
KALIBETRIEB SUD HARZ											
04 ROSSLEBEN	1905	-	0.32	-	-	700	-	50	R & P	-	
05 SONDERSHAUSEN	-	-	-	-	-	-	-	50	R & P	-	
06 SOLLSTEDT	1905	-	-	-	-	-	-	50	R & P	-	
07 BLEICHRODE	1902	-	-	-	-	-	-	50	R & P	-	
08 VOLKENRODA	1909	-	-	-	-	-	-	50	R & P	-	
09 BISCHOFFERODE	1915	-	0.510	-	-	-	-	50	R & P	-	
KALI-UND STEIN SALZBETRIEB SAALE											
10 TEUTSCHENTAL	1907	-	-	-	-	-	-	50	R & P	-	
KALIBETRIEB ZIELITZ											
11 ZIELITZ	1973		0.9	5.3	17	800	18-25	50	R & P	-	
RUSSIA **URALS**											
01 BEREZNIKI NOS.1-4	1931	15900	5.2-5.3	12.3-13.1	21	300-500	-	-	DOME & PILLAR	-	
02 SOLIKANSK NOS. 1&2	1931		1.4	3.5	14-15	200-500	-	-	ROOM & PILLAR	-	
03 NOVO SOLIKANSK	1983		1.9-2.0	4.5-5.0	14-15	200-500	-	-	ROOM & PILLAR	-	
BYELORUSSIA											
04 SOLIGORSK NOS. 1-4	1963 (no.1) 1978 (no.4)	2800	5.0-5.2	11.8-12.2	13.4-17.7	420-650	5.0	80-85 OVERALL 43-45 R&P 70-75 LONGWALL	R&P, LONGWALL	16000 SURF + U/G	
UKRAINE											
05 KALUSH - STEPNIK AREA	1923 (old) 1967 (new)	2900	0.4	0.9	8-12	100-300	19-27	90.5	R & P SHRINKAGE STOPING	-	

TABLE 5-5

SUMMARY OF PRINCIPAL CHARACTERISTICS OF UNDERGROUND POTASH MINES

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Letter of Transmittal

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Executive Summary (English)

Executive Summary (French)

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PART 2 STUDY METHODS

PART 3 CANADIAN POTASH MINING METHODS

PART 4 INTERNATIONAL POTASH MINING METHODS

PART 5 MINING METHODS SUMMARY

PART 6 ALTERNATIVE METHODS

PART 7 GEOTECHNICAL PROGRAM

PART 8 CONCLUSIONS

PART 9 RECOMMENDATIONS

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APPENDIX A QUESTIONNAIRE

APPENDIX B REFERENCES

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PART 1

INTRODUCTION

1.0 INTRODUCTION

This study was authorized on November 1983 by the Canadian Department of Supply and Services on behalf of the Department of Energy, Mines and Resources, CANMET Mining Research Laboratories.

The authorization to proceed was based on a proposal from Montreal Engineering Company, Limited, Calgary, dated 16 September 1983 in which the objectives and scope of work were defined as follows:

1.1 OBJECTIVES

The objective of the work was to identify alternatives to the methods presently used to mine potash or salt in Canada, with particular reference to those aspects that could result in lower mining costs and/or improved extraction ratios.

1.2 SCOPE OF WORK

The scope of work was:

(1) To review potash mining as practised around the world providing descriptions for each identified method of geological setting, overburden thickness and quality, ground control problems, production levels, productivity and costs.

(2) To identify the major parameters for and against the use of alternative mining methods in Saskatchewan and New Brunswick.

(3) To outline a geotechnical program which should be carried out before any alternative mining method can be implemented.

This project was assigned to the Mining Division of Montreal Engineering Company, Limited under the direction of Mr. A.M. Scott, Chief Mining Engineer.

Montreal Engineering were assisted in this work by Golder Associates who were responsible for the geotechnical aspects and Minco Consultants who were responsible for the geological aspects (Fig. 1-1).

We wish to acknowledge the help and encouragement which we have received from Dr. J. Pathak, Scientific Authority for the Project, and Dr. Gerhard Herget, of the Canmet Mining Research Laboratories.

1.3 ABBREVIATIONS

Table 1-1 lists the abbreviations used in this report.

1.4 DISCLAIMER

The opinions and interpretations presented in this report are those of the authors and do not necessarily represent those of the mining companies and other organizations who provided data and assistance.

FIGURE 1-1
CONTRACT RESPONSIBILITIES:

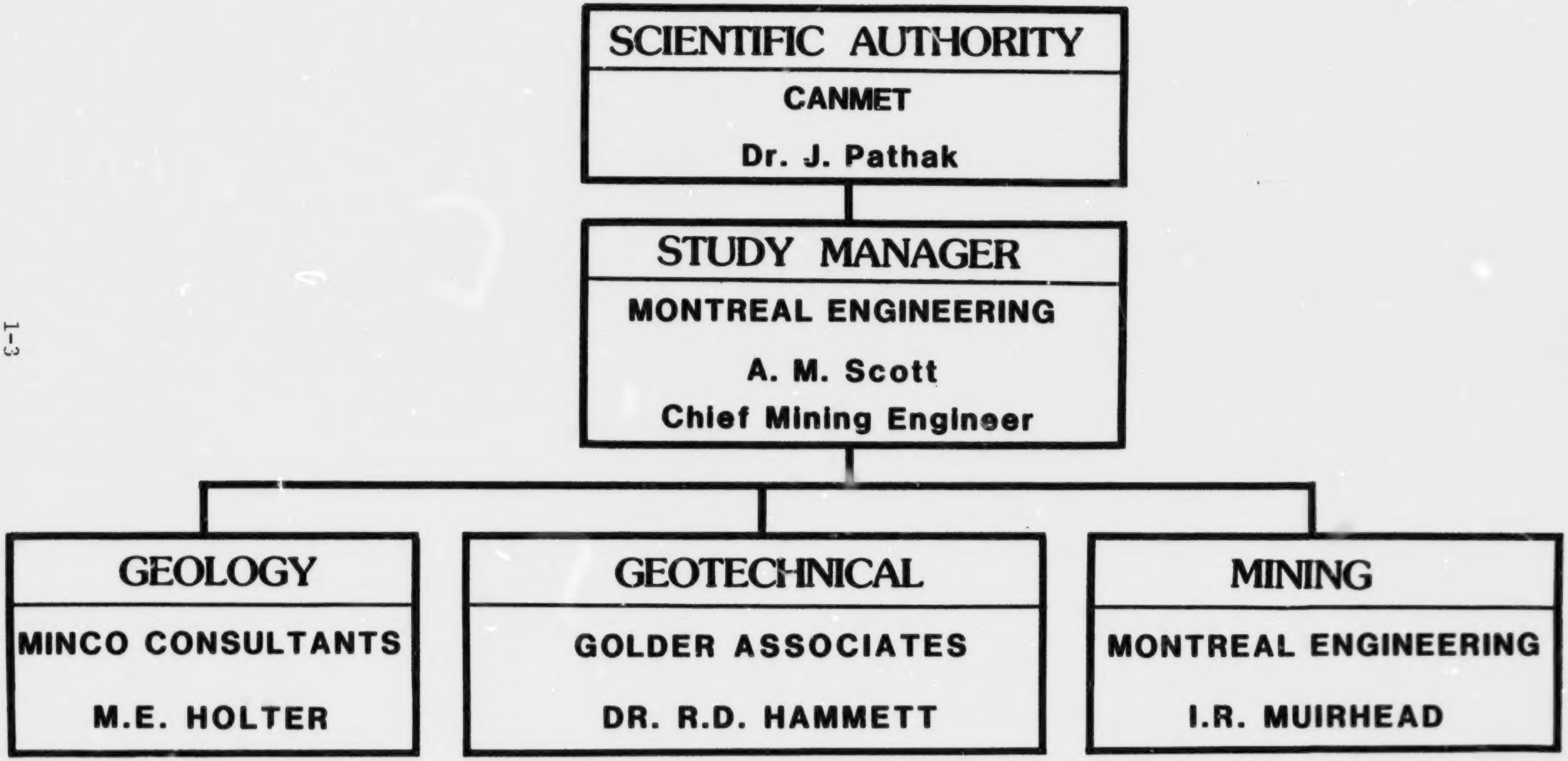
SCIENTIFIC AUTHORITY
CANMET
Dr. J. Pathak
STUDY MANAGER
MONTREAL ENGINEERING
A. M. Scott
Chief Mining Engineer
GEOLOGY
MINCO CONSULTANTS
M.E. HOLTER
GEOTECHNICAL
GOLDER ASSOCIATES
DR. R.D. HAMMETT
MINING
MONTREAL ENGINEERING
I.R. MUIRHEAD

TABLE 1-1

Abbreviations

mm	millimetre
cm	centimetre
m	metre
km	kilometre
ha	hectare
m^2	square metres
m^3	cubic metres
t	tonnes
l	litres
M	million
k	thousand
y	year
d	day
hr	hour
min	minute
s(sec)	second

PART 2

STUDY METHODS

PART 2 - STUDY METHODS

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2.0 STUDY METHODS

Potash is produced in some 14 countries around the world (Table 2-1) either by underground and surface mining methods, or by evaporation of surface and underground brines.

Underground mining methods are used in 10 countries which include Canada, USA, USSR, East Germany, West Germany, France, Spain, Italy, United Kingdom and China. In addition, the underground mining of potash is being investigated or developed in Brazil and Thailand.

In order to undertake a review of the mining methods used for the extraction of underground potash over such widespread locations around the world, three methods for sourcing data were identified. These were by (i) mine visits, (ii) literature search and (iii) questionnaires.

2.1 MINE VISITS

Visits were made to mines in Canada and USA. The mines were selected on the basis of location and mining method employed, in order to obtain as representative a sample as possible of geological, geotechnical and mining conditions. For budgetary reasons, visits were restricted to mines in Canada and USA.

The following mines were visited, including where relevant, underground operations:

Canada

Potash Company of America - Penobsquis Mine - Sussex, N.B.
International Minerals Corp. - K2 Mine - Esterhazy, Sask.
Potash Corporation of Saskatchewan - Cory Mine - Saskatoon, Sask.
Potash Corporation of Saskatchewan - Lanigan Mine - Saskatoon, Sask.
Central Canada Potash - Colonsay Mine - Colonsay, Sask.
Cominco - Vade Mine - Vanscoy, Sask.

U.S.A.

Kerr-McGee Chemical Corp. - Hobbs Mine - Carlsbad, N.M.
Mississippi Chemical Corp. - Carlsbad Mine - Carlsbad, N.M.
Amax Chemical Corp. - Carlsbad Mine - Carlsbad, N.M.
F.M.C. Corp. - Trona Mine - Green River, Wyo.
Texas Gulf Inc. - Cane Creek Mine - Moab, Utah

In addition, discussions were held with two Canadian Mining Companies who are developing potash mines in New Brunswick, namely:

B.P. Exploration Canada - Millstream Project, N.B.
Denison Mines - Saltspring Mine, N.B.

2.2 QUESTIONNAIRE

In order to obtain information from overseas mining companies, a questionnaire (in English - see Appendix A) covering geological, geotechnical and mining aspects was prepared and issued to potash mining companies and mines listed below, together with a covering letter in the appropriate language.

Country	Company	Mine
U.K.	Cleveland Potash	Boulby
France	Mines des Potase d'Alsace (MDPA)	Marie-Louise Amelie Theodore
Spain	Union Explosivos Rio Tinto (ERT)	Llobregat Cardona
	Minas de Potasa de Suria	Suria
	Minas de Potasa de Navarra (PDN)	Navarra
Italy	Industria Sali Potassici E Affini (ISPEA)	Racalmuto Pasquasaia Corvillo San Cataldo/Palo Realmonte
W. Germany	Kali-und Salz	Wintershall Braunschwieg-Lueneberg Sigmundshall Siegfried-Giesen Salzdetfurth Niedersachsen-Riedel Neuhof-Ellers Hattorf Bergmannsegen-Hugo
E. Germany	VEB Kalibetrieb Zielitz	Zielitz
	VEB Kalibetrieb Saale	Teutschenthal
	VEB Kalibetrieb Sud Hartz	Sollstedt

Country	Company	Mine
E. Germany (cont'd)		Bischofferode
		Bliecherode
		Volkenroda
		Sondershausen
		Rossleben
	VEB Kalibetrieb Werra	Dornoff
		Merkers
		Unterbreizbach
U.S.S.R.	Ministry of Geology	-
	Ministry of Chemical Fertilizer	-
Thailand	Ministry of Mineral Resources	-
Brazil	Engenharia Arplan SA	Sergipe

Information was also requested for potash mines in Canada and USA which were not visited, namely:

Canada	P.C.A.	Patience Lake, Sask.
	PPG Industries	Kalium, Sask.
U.S.A.	P.C.A.	Carlsbad, N.M.
	National Potash Company	Lea, N.M.
	Duval Corporation	Carlsbad, N.M.
	IMC	Carlsbad, N.M.

2.3 LITERATURE SEARCH

Searches were made in mining and related databases for technical articles and relevant information covering geological, geotechnical and mining aspects.

Databases in North America and Europe were accessed as follows:

N. America

COMPENDEX
NTIS
Ei MEETINGS
MINTEC (CANMET)
GEO REF
SCI SEARCH
USGPO
INSPEC
ISMEC
AGRICOLA
CHEMICAL ABSTRACTS

Europe

MTEC (English)
IMM (English)
PASCAL (French)
GEOLINE (German)

Technical articles on European potash mining operations were also provided by:

- Anderson Strathclyde PLC, Glasgow U.K.
- P.C.S., Saskatoon
- M.R.L., Ottawa
- CISTI, Ottawa

2.4 RESULTS OF INFORMATION SOURCING

As one might have expected from an industry so intensively competitive internationally as the potash industry, no information was made available on costs (capital or operating) and in many cases, even productivity figures were classed as being confidential.

The mine visits, naturally, provided the most useful information on geology and mining methods and conditions.

The results from the worldwide questionnaire were most disappointing. Of the 43 letters and questionnaires which were issued, only six (14%) replies were received, well below the average response (35%) from previous similar mining surveys. (Another indication perhaps of the competitive nature of the industry.)

The literature search proved more rewarding, identifying over 280 articles covering the world wide operations of the potash mining industry. These, together with the Survey of World Potash Resources (3rd ed.) published by the British Sulphur Corporation, formed the basis of the data presented on the underground mining of potash outside North America.

In addition, Monenco's staff and in-house library contributed much personal and filed knowledge on other forms of mining including the use of backfill in sectors of the underground mining industry outside potash.

2.5 ACKNOWLEDGEMENTS

Much of the information used to compile this report has come from the mining companies, equipment manufacturers, and the multitude of published technical articles. We have listed these in Appendix B - References, and wish to acknowledge that without the help of the company officials and the author's efforts, this work would have been more difficult to accomplish.

2.6 REFERENCES

The material presented in the following sections has been drawn from the more than 280 references identified in the study. These references are given in Appendix B under General, Country and specialized subject headings. The section on Spain, for example, is based on the general references and the twenty specific references dealing with Spanish potash.

TABLE 2-1

World Wide Potash Production 1982/3

Country	Production ($kt\ K_2O$)	Surface (S) or Underground (U)
USSR	8,079	U
Canada	5,379	U
E. Germany	3,434	U
W. germany	2,226	U
U.S.A.	1,639	U
France	1,601	U
Israel	946	S
Spain	702	U
U.K.	263	U
Italy	127	U
China	25	US
Chile	21	S
Others	9	S
	24,451	

PART 3

CANADIAN POTASH MINING METHODS

PART 3 - CANADIAN POTASH MINING METHODS

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3.0 CANADIAN POTASH

3.1 GENERAL

Canada is the second largest producer of potash in the world (after the USSR), although by mining industry standards, it is a very young industry, being barely 25 years old.

Potash is mined in two provinces in Canada - Saskatchewan and New Brunswick - and deposits are known to exist in Manitoba.

In Saskatchewan, underground production by conventional methods is in two areas, the central area around Saskatoon, and the south east area around Esterhazy. In addition, there is one solution mine just west of Regina.

In New Brunswick, there is one producing mine, one under construction, and one under development, generally located in the region of Sussex.

In this section, we have described the general geology of the potash areas, summarized the major details of the various operating or planned mines, provided a more detailed description of a typical mine for each mining method, and finally endeavoured to summarize the major constraints on the mining operations. Table 3-1 lists the mines in Saskatchewan and New Brunswick.

TABLE 3-1

Canadian Potash Mines

Mine	Zone Worked	Depth (m)	Production Year
New Brunswick			
PCA - Penobsquis	Dunsinane	460 - 760	1983
Denison - Saltsprings	Marchbank	580 - 850	1985
BP - Millstream	Case	845 - 1220	?
Saskchewan (Central)			
PCA - Patience Lake	Patience Lake (U)	1016	1958
PCS - Allen	Patience Lake (U & L)	1036	1968
PCS - Cory	Patience Lake (U)	1012	1968
PCS - Lanigan	Patience Lake (U & L)	1006	1968
Cominco - Vade	Patience Lake (U)	1076	1969
CCP - Colonsay	Patience Lake (U)	1021	1969
Saskatchewan (Southeast)			
IMC - K1	Esterhazy	955	1962
IMC - K2	Esterhazy	955	1967
PCS - Rocanville	Esterhazy	960	1970
Saskatchewan (South)			
PPG - Kalium	Patience Lake, Belle Plains, Esterhazy	1730	1960

3.2 SASKATCHEWAN (SASKATOON)

321 GEOLOGICAL ASPECTS

The commercial potash beds of Saskatchewan are of Middle Devonian age and occur at the distal end of the Elk Point Basin within the Prairie Evaporite Formation. The regional setting is shown in Figure 3-1. Three major sylvinite zones have been identified and are designated, in ascending order as: the Esterhazy, Belle Plaine, and Patience Lake Members. Each member may attain a maximum thickness of over 30 metres and may be correlated with ease across the entire potash subbasin. Of the eight operating underground mines, six are producing potash from sections of the Patience Lake Member and the two most easterly mines have been developed within the Esterhazy Member. Figure 3-2 shows the location of the potash mines in Saskatchewan. Little public information is available on the production zones at the one solution mine operating in south central Saskatchewan. Figures 3-3 and 3-4 shows sections of the Evaporite Formation of Saskatchewan.

The potash beds are relatively flat-lying with only gentle dips (1/2°- 1°) occurring towards the south and southwest. Depths to the top of the Prairie Evaporite varies accordingly from about 600 metres along the subcrop to approximately 2700 metres near the U.S. Boundary. Conventional underground mining has been confined to potash zones at depths of about 1000 metres. Table 3-2 shows various characteristics of the potash mines in Saskatchewan.

The salt-back cover on the Esterhazy, or lowest member, is normally well over 15 metres. The Belle Plaine Member is overlain by somewhat less salt (6 metres or more) and the uppermost, or Patience Lake Member, is covered by 6 metres or less of barren salt. The

TABLE 3-2

Saskatchewan Potash Mines

Mine	Potash Member	Depth (m)	Mining thickness (m)	K_2O (%)	Insols. (%)	Reserves (Mt)
		Conventional Underground Mine				
Cominco, Vade	Patience Lake	1061-1123		25-30	5	112
CCP, Colonsay	Patience Lake	1021	2.9-3.4	27.5		600
PCA, Saskatoon	Patience Lake	1016	4	27		
APM, Allan	Patience Lake	1036	3.35	27.3	5.0	2600
PCS, Cory	Patience Lake	1012	3	26		361
PCS, Lanigan	Patience Lake	985-1077	5	23	6.0	
PCS, Rocanville	Esterhazy	960	3	27	4.0	314
IMC Esterhazy	Esterhazy	955	2.5	25-35	0.5-2.0	
		Solution Mine				
Kalium, Belle Plaine		1730				

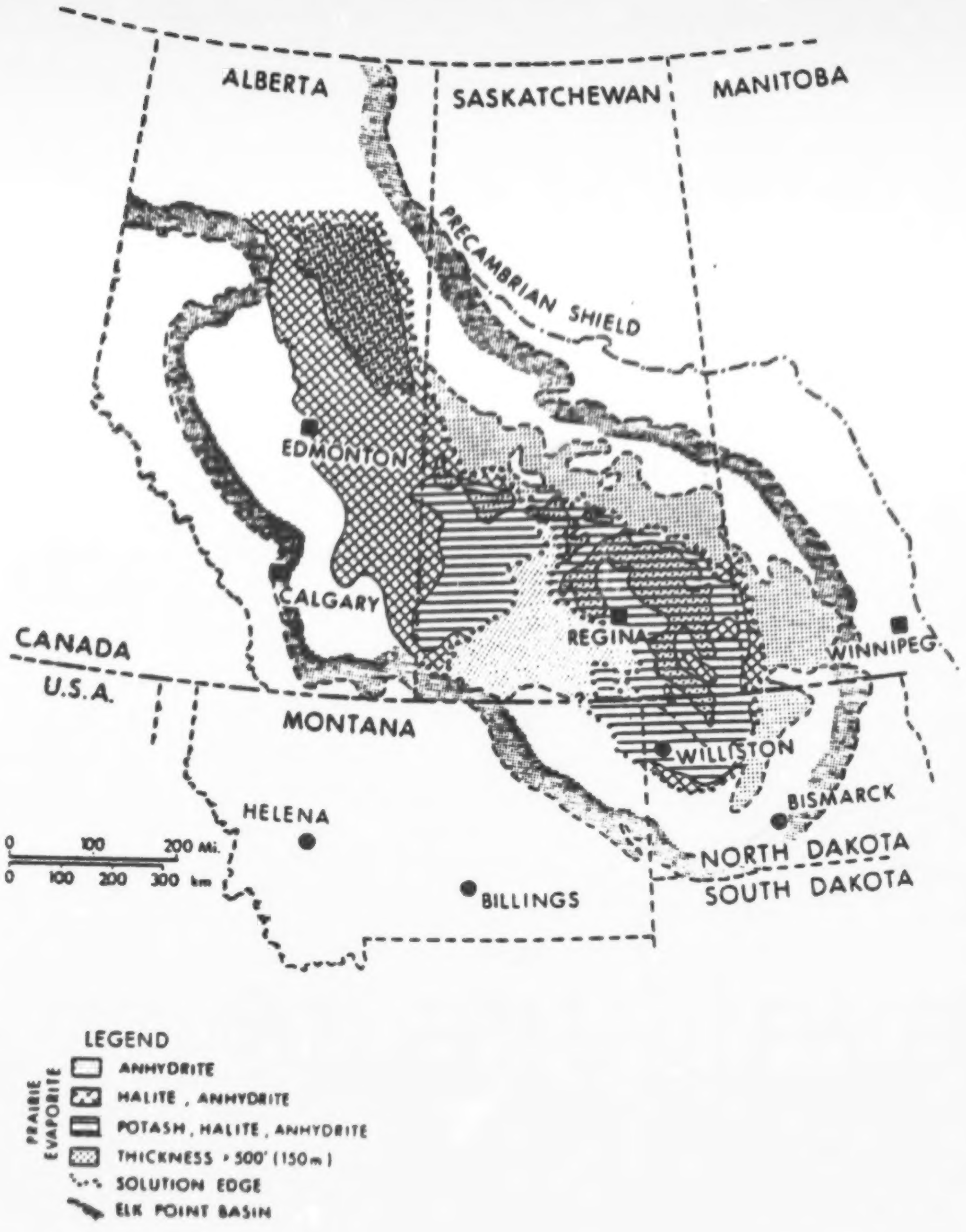

ALBERTA
SASKATCHEWAN
MANITOBA
PRECAMBRIAN SHIELD
EDMONTON
CALGARY
REGINA
WINNIPEG
CANADA
U.S.A.
MONTANA
WILLISTON
BISMARCK
HELENA
NORTH DAKOTA
SOUTH DAKOTA
BILLINGS
0 100 200 Mi.
0 100 200 300 km
LEGEND
PRAIRIE EVAPORITE
ANHYDRITE
HALITE, ANHYDRITE
POTASH, HALITE, ANHYDRITE
THICKNESS > 500' (150 m)
SOLUTION EDGE
ELK POINT BASIN

FIGURE 3-1 SASKATCHEWAN - REGIONAL GEOLOGY

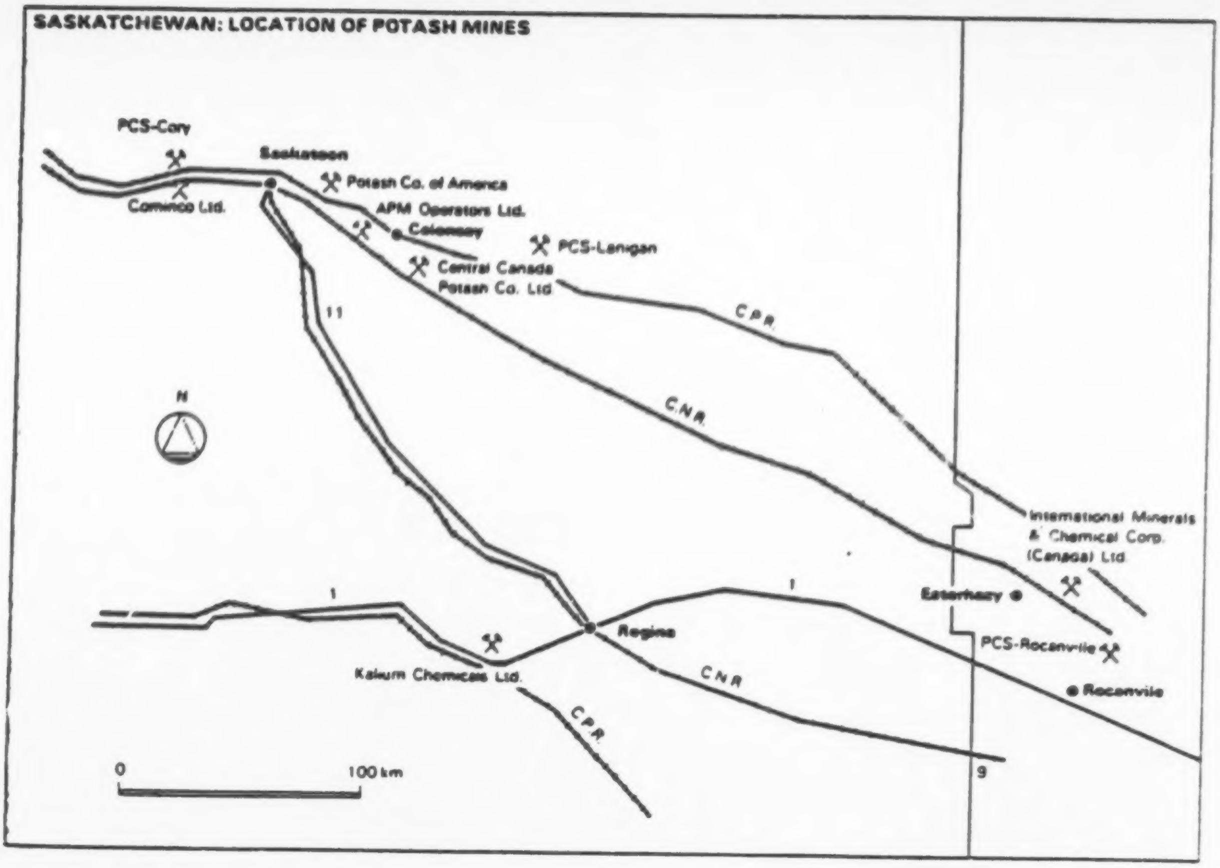

SASKATCHEWAN: LOCATION OF POTASH MINES
PCS-Cory
Saskatoon
Potash Co. of America
APM Operators Ltd.
Colonsay
Cominco Ltd.
PCS-Lanigan
Central Canada
Potash Co. Ltd.
C.P.R.
11
C.N.R.
N
International Minerals
& Chemical Corp.
(Canada) Ltd.
1
1
Esterhazy
Regina
PCS-Rocanville
Kalium Chemicals Ltd.
C.N.R.
Rocanville
C.P.R.
0
100 km
9

FIGURE 3-2
LOCATION OF POTASH MINES - SASKATCHEWAN

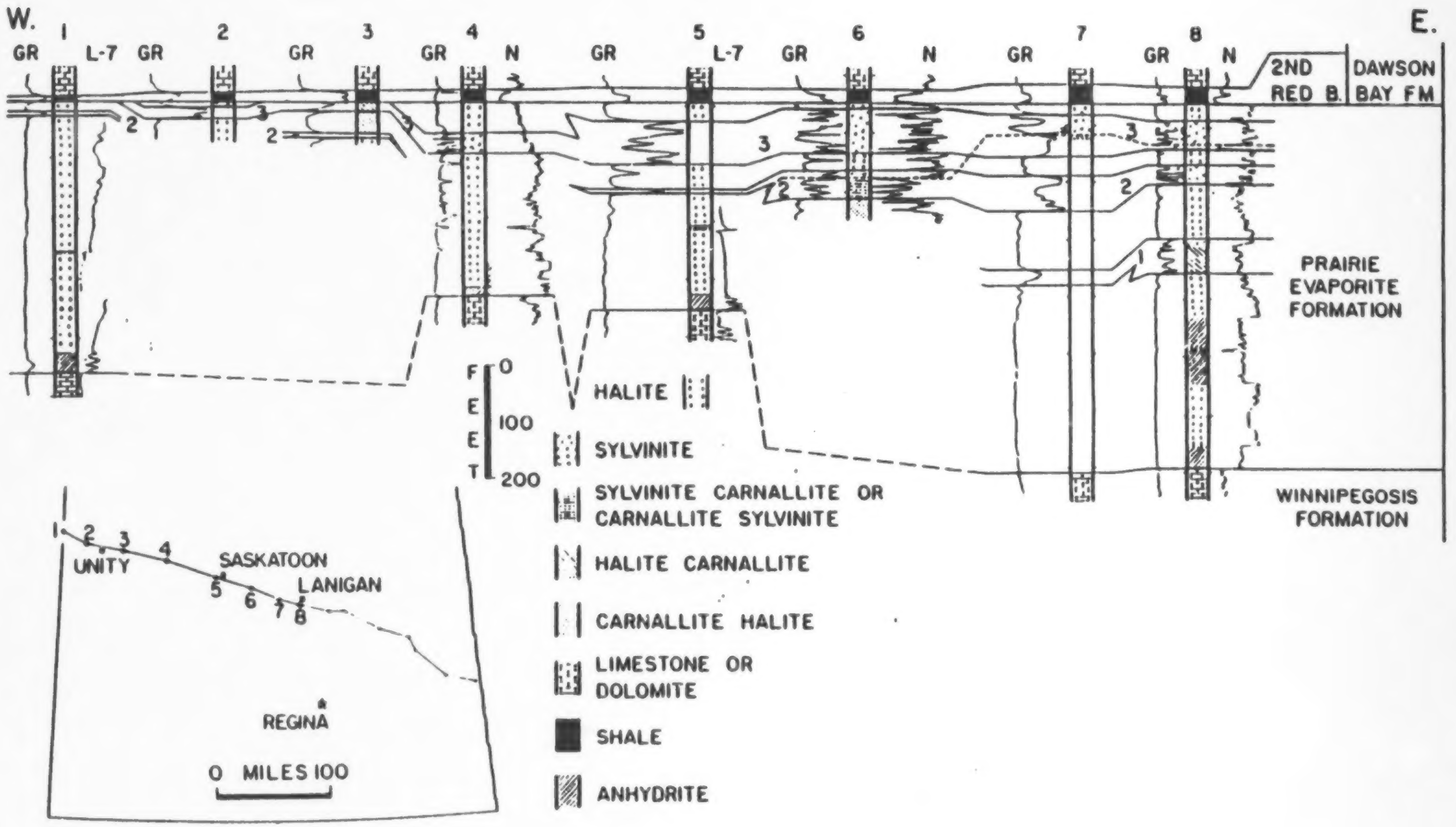

W.
E.
GR
L-7
N
1
2
3
4
5
6
7
8
2ND RED B.
DAWSON BAY FM
PRAIRIE EVAPORITE FORMATION
WINNIPEGOSIS FORMATION
FEET
0
100
200
HALITE
SYLVINITE
SYLVINITE CARNALLITE OR CARNALLITE SYLVINITE
HALITE CARNALLITE
CARNALLITE HALITE
LIMESTONE OR DOLOMITE
SHALE
ANHYDRITE
UNITY
SASKATOON
LANIGAN
REGINA
0 MILES 100

FIGURE 3-3 SECTION-EVAPORITE FORMATIONS

UNITY TO LANIGAN

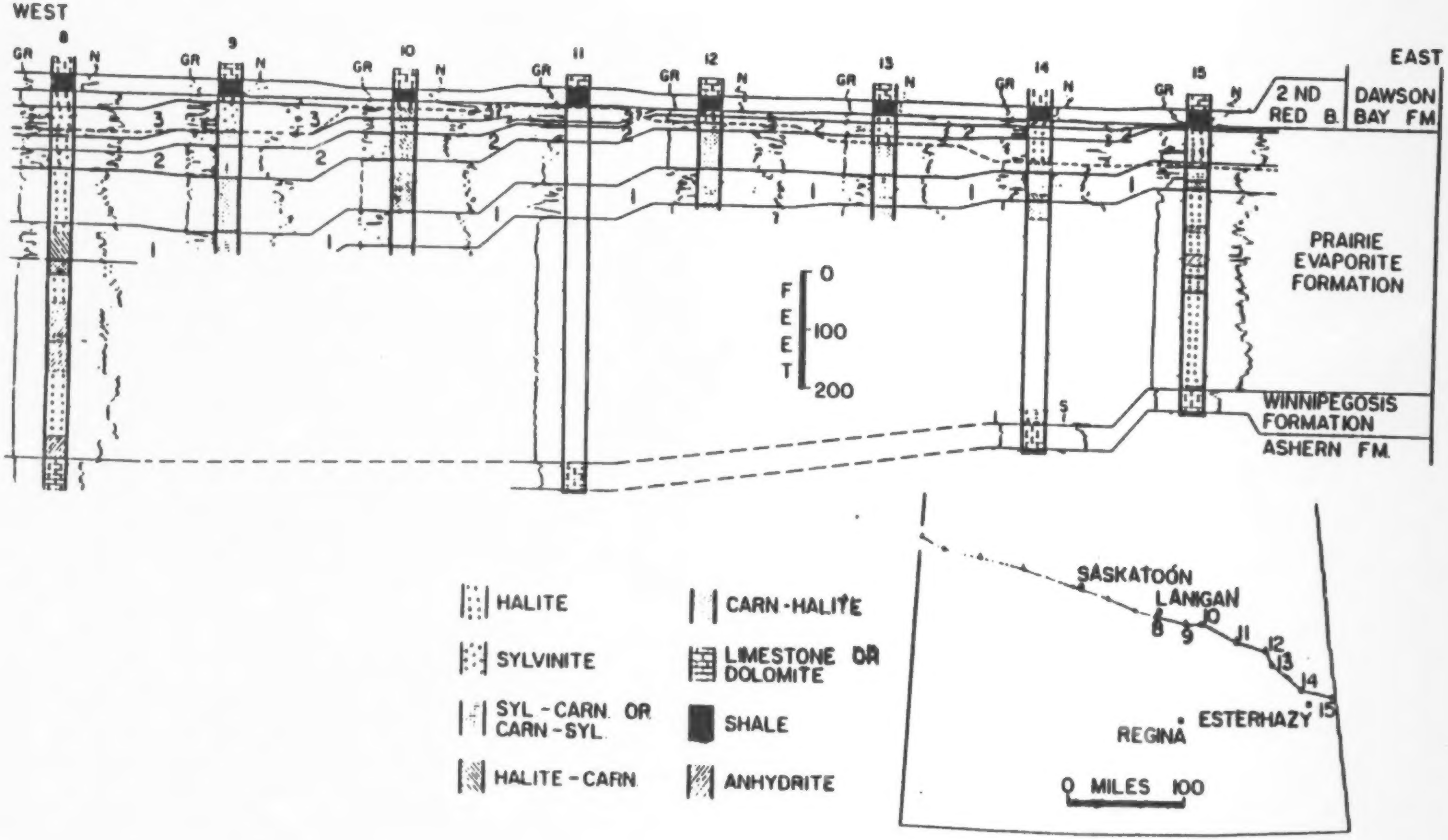

WEST
EAST
GR
N
8
9
10
11
12
13
14
15
1
2
3
S
2 ND RED B.
DAWSON BAY FM
PRAIRIE EVAPORITE FORMATION
WINNIPEGOSIS FORMATION
ASHERN FM.
FEET
0
100
200
HALITE
SYLVINITE
SYL.-CARN. OR CARN.-SYL.
HALITE-CARN.
CARN.-HALITE
LIMESTONE OR DOLOMITE
SHALE
ANHYDRITE
SASKATOON
LANIGAN
REGINA
ESTERHAZY
0 MILES 100

FIGURE 3-4 SECTION-EVAPORITE FORMATIONS
LANIGAN TO ESTERHAZY

amount of protective salt above the potash beds may be vastly altered by localized solution phenomena.

Although much of the region is underlain by sylvinitic ores certain areas have been determined to be highly carnallitic. For example, each member has a carnallite-rich margin on all sides of its areal distribution except to the south. Stratigraphically lower members have lesser amounts of carnallite and the affected margins are narrower.

Potash grades of up to 30 percent sylvite (18 percent K_2O are common for all three members). Mining grades currently run between 23 to 35 percent K_2O for underground operations with the most common ore value reported to be 27 percent K_2O. Lateral continuity of grades is normally only affected by the presence of salt horses.

Insolubles may occur as distinct beds or as finely disseminated layers within the potash intervals. Individual stratigraphic details may be traced with little difficulty across any one mine property. In general, the percentages of insolubles increase across the subbasin to the south and are locally high near regions rich in carnallite. Insoluble contents tend to increase in successively higher potash members. Within the areas currently under development by conventional underground mining methods the percentages of insolubles may commonly range from 2.0 to 6.0 percent.

At least two geological phenomena may be considered to require close monitoring for effective mine control and optimum grade production. Maintenance of a reasonable salt-back is considered to be one factor of great importance to ensure that overlying formation waters do not invade the operating mine. Post-Prairie Evaporite solution channels in areas ahead of the mine face must therefore have early detection to ensure the security of the mining operations. In addition, the presence of salt horses (unless they are of the sylvite-rich variety) will obviously adversely affect the normal extraction of acceptable ore grade material.

322 MINING ASPECTS

Six mines are operating in the Saskatoon district. Three of these mines are operated by Potash Corporation of Saskatchewan, namely: Cory, Lanigan and Allan (60% holding). Noranda Mines Ltd. own Central Canada Potash at Colonsay, Cominco Ltd. owns a mine at Vanscoy and Potash Co. of America owns a mine at Saskatoon.

Potash Co. of America operated the first potash mine in Saskatchewan and mining commenced in 1958. However production ceased in 1959 because of water seepage in the shaft. In 1960 work began on grouting the shaft and modifications were made to the refinery. Production began again in 1965 and a second shaft was begun in 1966. Capacity is stated to be 420,000 t of K_2O per year. The mining method is by long room and pillar using continuous mining machines and conveyor belts.

U.S. Borax and Chemical Co. began sinking two shafts for the Allan Potash Mine in 1964. In 1965 two other companies participated in the venture: Homestake Mining Co. of San Francisco, California and Swift Canadian, Ltd. of Toronto. Work on No. 1 shaft was delayed because of an inflow of water from the base of the Blairmore Formation. The flooding was eventually stopped and production began in 1969. Homestake sold its 40% interest to Texas-Gulf. In 1978 the Potash Corporation acquired the interest of Borax and Swift Canadian Co. while Texas-Gulf retained a 40% holding. Capacity is stated to be 970,000 t of K_2O per year.

The mining method employed in a panel is a chevron pattern with three entries driven 1000 m perpendicular to the main entries. The centre entry is driven double pass or about 10.8 m wide. The outer entries that parallel the centre entry, each with centre lines 14 m from the middle entry, are driven single pass. These outer entries are used for intake and exhaust air. The chevron pattern begins after the centre entry has been driven 90 m from the main entry. The wings of the chevron are inclined at 45° to the centre entry and are driven double pass for 35 m. The wings are driven symmetrically. This chevron cycle is repeated until the 1000 m entry is cut. The mining is performed by continuous twin-rotor borer machines. A floor mounted conveyor is installed in the panel that is connected to an extensible conveyor which follows the mining machine. Allan potash mine has begun to utilise the potash level below the present upper mining level for transporting ore and equipment to the shaft as this level is more stable.

Alwinsal Potash of Canada Ltd. was formed in 1956 as a joint Franco-German enterprise. Sinking of the first shaft began in 1964 and the mine came into production in 1968. The Potash Company of Saskatchewan acquired the mine in 1977 when it became the Lanigan Division of PCS. The second shaft was completed in 1978. Capacity is stated to be 625,000 to of K_2O per year with planned capacity in 1985 to be 1 740 000 t of K_2O per year.

The shaft at Lanigan was constructed in a different manner to the other shafts in the area which used cast-iron tubs. One-third of the depth of the shaft is lined with a double wall of welded steel between which there is a layer of high strength concrete with an additional layer of concrete backfill protecting the outer steel wall.

In the Lanigan area there are four potash zones. The second highest or "B" zone is mined. The other mines in the Saskatoon area mine the uppermost potash seam. The lower two zones are carnallitic.

The "B" zone is slightly lower grade of potash than the upper zone but the ground stability is better. The mining method is room and pillar with the length of the rooms varying between 1220 and 1400 m and width being 10.4 m. Seventeen metre wide pillars separate the rooms. The continuous miners take either two or four passes in a room. The ore is fed onto an extensible belt or cross-conveyor if on second pass. The Lanigan Division is experimenting with the "Orebiter" miner that incorporates two cutter booms of 300 KW each that are mounted on a four-rotor Marietta 780AW-4 borer miner. This machine is expected to result in a 40% higher seam recovery because it will be able to mine to a greater height (5.2 m) compared with the standard machine (3.65 m).

Cominco Ltd. began sinking two shafts at Vanscoy, Saskatchewan in 1965. Cominco developed the deepest mine in the province with the shafts reaching the depth of 1143 and 1091 m. Production began in 1969. In August 1970 the mine flooded and production did not begin again until late 1972. Capacity is stated to be 500,000 t of K_2O.

The mining is carried out on a modified room and pillar system. The entries are either three or four entry system with the outside entries being driven first to relieve the pressure on the inner one or two entries. Two-rotor Marietta miners cut an open 5.4 m wide by 3.4 m high. Long and short rooms are used in developing panels. The long rooms are 1800 m and the short rooms 625 m. In mining the rooms the first pass of a room is cut the full length. Brattice cloth separates the fresh air from the exhaust air. The extensible conveyor used to convey the potash is in the exhaust side of the room.

After the miner completes the first pass it reverses and then takes the second pass. The resulting width of the room is 9.8 to 10.4 m wide. The pillar left between rooms are 5.5 to 6.7 m wide. Six rooms are mined then a main pillar of 30 to 58 m wide is left.

The mine at Cory, Saskatchewan was developed by Duval Corp. a subsidiary of Pennzoil United, Inc. and began sinking two shafts in 1965. Production commenced in 1969. In 1976 Potash Corporation of Saskatchewan acquired the mine at Cory. This was the first purchase made by PCS. The stated capacity of the plant is 830,000 t of K_2O per year. The present mining method is by room and pillar employing a chevron pattern. The panel has three main entries with the centre entry being two and one-half passes wide; the other entries are two passes wide. The chevron wings are cut three passes wide and are 13.1 m wide with a few being cut 17 m wide. The equipment employed is mainly two rotor Goodman continuous miners. The miner is connected to seven bridge conveyors and a crusher before depositing the ore onto a 914 mm wide panel conveyor belt. Potash is fed onto 1066 mm wide mainline conveyors and then onto a 1220 mm wide conveyor for transport to the underground storage bins.

The above brief descriptions of five of the potash mines in the Saskatoon district present only a general description of the mining methods employed. The sixth mine in the Saskatoon district has been chosen for a more detailed description. This mine, Central Canada Potash Ltd. at Colonsay, Saskatchewan is wholly owned by Noranda Mines Ltd.

The overall regional geological description as stated previously applies. The following indicates the local geological aspects in more detail. The potash beds are part of the middle Devonian Prairie Evaporate Formation which was deposited in the Elk Point Basin. Figure 3-3 illustrates the geological sequence. The Winnipegosis Formation is overlain by the Prairie Evaporate Formation and in turn overlain by the Second Red Beds, the Dawson Bay Limestones and then the First Red Bed. The two Red Beds consist of clay, mudstone and shale.

The potash beds are found in the top 31 m of the Prairie Evaporate Formation below the Second Red Bed. There are three mineable potash beds at Central Canada, denoted as zones 3, 2 and 1. The two top beds are economical to mine the third bed is not attractive. In the upper bed (zone 3), 3.4 metres of potash is being mined.

Seventeen surface holes have been drilled plus other holes have been drilled up from underground mine development headings. A 90 m radius pillar is left around each drillhole and 1000 m radius shaft pillar has been left around the shaft except for the necessary development heading to connect the mine to the shaft. Potash reserves are nearly 500 million tonnes averaging 27% K_2O.

Over 40,400 ha have been covered in surface and geophysical surveys. Seismic surveys conducted in Blocks 1, 2, 3 and 4 have been a good aid in development planning. Salt horses occur but do not appear to have had too much effect on the overall mining plans. Wash out areas and natural caverns have not been found.

The salt back averages around 11 m and ranges between 8.5 m and 18.3 m.

Noranda Mines Ltd. began work on the site in 1965. Two 4.9 m diameter shafts were sunk 135 m apart to reach to potash beds at 1020 metres below surface. Freezing methods were employed to sink through the Blairmore and Devonian water-bearing formations. Cast-iron tubbing was used to form the lining through these sections. Mining operations began producing potash in 1969. Four Marietta 911A continuous miners along with gathering-arm loaders and electric shuttle cars were used to mine in a room and pillar system leaving square pillars. Figure 3-5 shows this mining system and indeed illustrates the evolution of the room and pillar mining system. The present method of mining is now a chevron plan or a hybrid of the chevron plan.

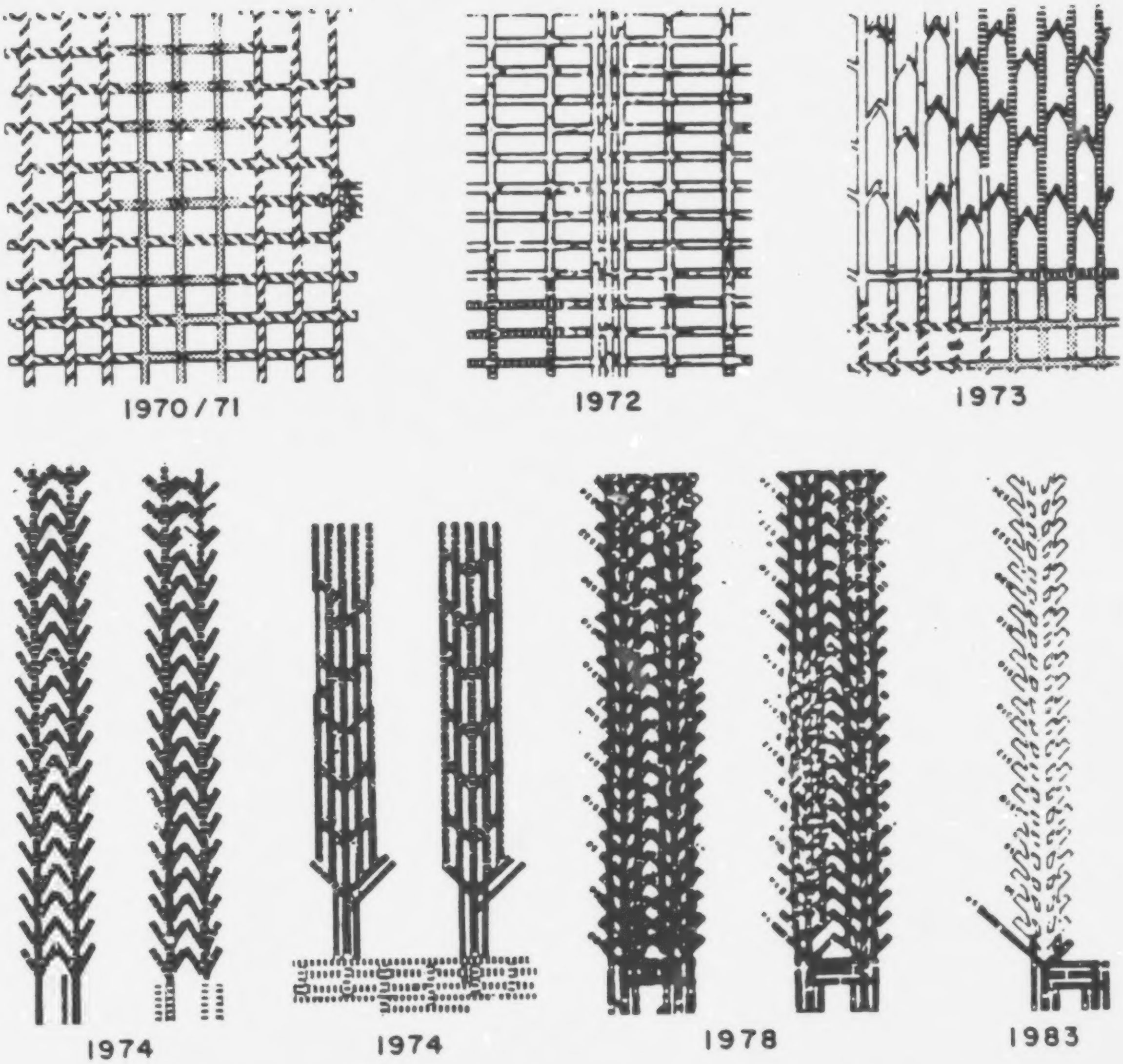

1970/71
1972
1973
1974
1974
1978
1983

FIGURE 3-5 EVOLUTION OF ROOM AND PILLAR MINING SYSTEM IN A SASKATCHEWAN POTASH MINE

To produce the planned production of 3.1 million tonnes of ore per year or 1.27 million tonnes of K_2O equivalent the following mining equipment is used.

5 - Marietta Miners (911A) with portable conveyor bridges
1 - Goodman Borer (526)
1 - AM 100 Alpine Miner
1 - AM 50 Alpine Miner
1 - Undercutter
2 - Scoop trams

The make-up of mining equipment in the development of a chevron mining pattern is a 911A Marietta miner followed by three portable bridge conveyors which in turn deposit ore onto a 914 mm wide extensible conveyor. The ore is passed through a Stamler breaker and onto a 1066 mm or 1220 mm wide mainline conveyor for transport of the potash ore to underground storage bins. Figure 3-6 illustrates the schematics of the underground storage and surface storage. The production hoists are Koepe which travel at 16.8 m/s and can transport 24.5 t per skip; however, at the present time only 21.8 t are loaded.

Miners and equipment are transported throughout the mine by diesel carriers and trucks.

The power system capacity is 30 MVA: 14 MVA underground, 16 MVA surface. Peak capacity is about 23 MVA at the present time, with a resulting split of 10.7 for underground and 12.3 for surface. The power is delivered to the mine at 72 kV and is reduced to 13.8 kV for the mine and then to 4160 V for the miners and pumps. The mill is also supplied at 4160 V.

The mine works seven days a week, 24 hours per day. Working time at the face is 6 1/2 hours: travel time is one-half hour

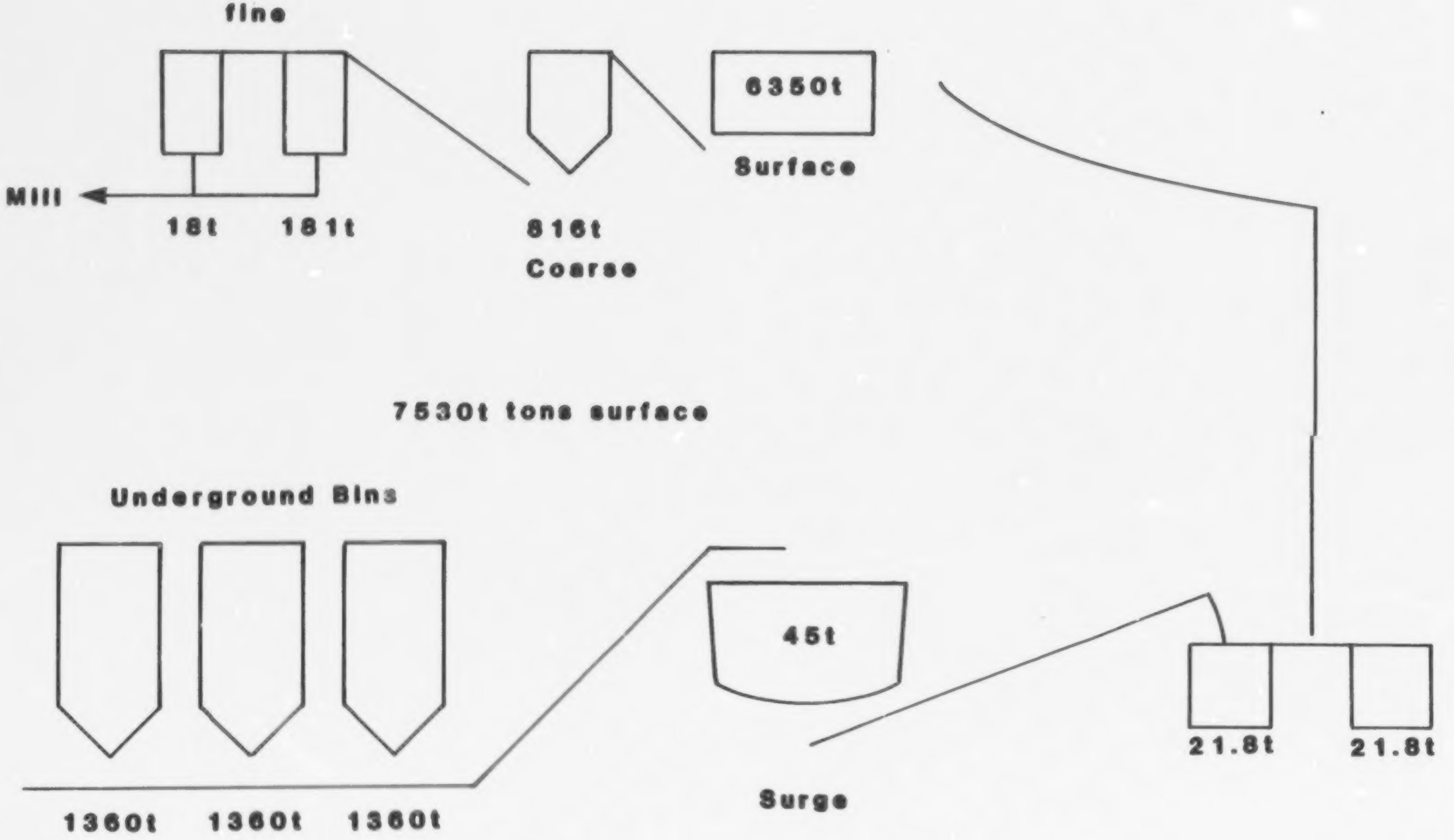

fine
Mill
18t
181t
816t
Coarse
6350t
Surface
7530t tons surface
Underground Bins
1360t
1360t
1360t
45t
Surge
21.8t
21.8t

FIGURE 3-6 SCHEMATIC OF UNDERGROUND AND SURFACE STORAGE - SASKATCHEWAN

each way and one-half hour for lunch. The mine is plannned to work 340 days out of the year.

Central Canada Potash's manning list is as follows:

86 - men - mine, construction, shaft
5 - hoistmen
66 - electrical and mechanical personnel
9 - supervisors mechanical & electrical
16 - mine supervisors

Maintenance requirements are that one miner is serviced for mechanical maintenance on a Wednesday and for electrical maintenance on a Tuesday. Each miner is lubricated and minor maintenance carried out each 24 hours. Depending on the mine method used the utilization of a mining system may vary from 20 perent to 40 percent and the availability from 65 to 95 percent with median occurring at 32 percent and 87.5 percent respectively.

The exhaust and intake ventilation system moves 122.7 m^3/s. There are booster fans along the fresh air intakes. Thirty-seven kilowatt fans move the air at 14.2 m^3/s. There are three fans in a room: one blows fresh air into a room, one exhausts heat and dust from the miner, and one exhausts air from the room.

The ambient temperature of the mine is 29°C and the relative humidity is 20%.

Water trucks are used to help settle dust on the roads. Dust control at Central Canada's Mine as in all potash mines in Saskatchewan is a significant problem.

The waste salt, clay and brines are deposited on a surface tailings pond. Of 2.4 tonnes of ore mined, one tonne of potash is produced and 1.4 tonnes of a mixture of salt and clay is deposited into the tailing pond. The tailing pond has a lining of natural clay and clay from the tailings adds to the total amount. The clay prevents the salt brine from contaminating the surrounding ground. Water wells in the surrounding area have been checked for contamination but none has been found.

One hundred and thirty-five tonnes of effluent are discharged from the mill stacks each year. This is composed mainly of KCl with some NaCl.

Some surplus brines, major rainfall and snowfall run-offs are pumped for use in the mill. Excess brines and run-off water are pumped into the Deadwood Sands aquifer at a depth of 1680 metres from surface. The brine injection is 38 litres per sec at an approximate pressure of 4 Mpa. In the summer up 4.5 million lites per day have been pumped.

Training sessions are conducted and classes usually consist of four men or women at a time. The training is a modular system which was developed by Noranda's head office in Timmins, Ontario. They also have an apprentice program.

The mining methods and planning concepts were changed mainly to incorporate rock mechanic concepts and to improve the safety of the back. Percent recovery or productivity has only increased marginally. CCP continues to review and investigate new methods and ideas, but there are no plans at present to change their mining method.

323 GEOTECHNICAL ASPECTS

Potash mining in the aforemention district is undertaken using long room and pillar, or chevron mining systems at a depth of betwen 1000 and 1075 m below surface.

The mining seams are approximately horizontal. The maximum thickness of salts in the back is approximately 15 metres and it is generally believed that a minimum of six metres is required to guarantee stable openings and to protect mine workings from possible water inflows. Some investigators have indicated that the lower part of the Dawson Bay limestone is plugged with halite, although large volumes of water may exist at higher elevations.

Water inflows have been experienced in some of the Saskatoon district mines, although these appear to be generally under control. A diamond drilling program conducted after an inflow to one of the mines indicated that the thickness of salt overlying the mine was abnormally thin, and that the brine was located in the Dawson Bay limestone.

Ground control problems are more severe in mines in the Saskatoon district than in the Esterhazy area. This is partly attributed to the increased mining depths in the Saskatoon mines and partly to the more prominent clay seams in the back. These problems include reduced roof stability, increased fracturing of the pillar walls, increased floor heave and high closure rates.

The original method of mining in some of the mines in the area utilized a room and pillar system with conventional square or rectangular pillars. However, in order to improve safety of the back and reduce spalling, long rooms or the chevron system was adopted. Many of the mines also embarked on retreat mining schemes. Typical extractions are 65 percent in the mining panels and 35 to 45 percent overall. Mechanically anchored and resin grouted rock bolts are used where required and in some mines roof support is quite extensive.

In the chevron system typical room widths are 7.5 to 10.5 m and typical wing widths are 9 to 15 m. Mining block widths are typically 170 to 200 m from wing to wing. Pillars between mining blocks are usually 75 to 90 m wide.

In the long room mining, the room width is typically 10 m and the pillar width 6 m. Six rooms are mined and then a main pillar 45 to 60 m wide is left between the mining panels.

Access to the mining blocks is generally by the three or four entry system with outside entries driven first to reduce the back stress on the inner one or two entries. Sequencing is also controlled in order that extraction does not take place in highly stressed areas that have not had time to redistribute stresses through creep processes.

Subsidence occurs over all of the mines, although this poses no significant problem.

In the past, mining has been primarily restricted to one seam and for most of the mines in the Saskatoon district this is the upermost economic seam. However, several mines are presently investigating mining a lower seam beneath the previously mined upper seam, with a separation distance of typically eight metres. Initial tests that have been done in one of the mines indicates a significantly higher degree of stability in the underlying excavations than was experienced during the mining of the initial excavations. This is possibly due to the underlying excavations being made in a favourable stress environment as a result of stress readjustments around the initial excavations.

One of the mines in the Saskatoon district has experienced increased seismic activity over the past five years. This activity has been monitored extensively using a seismic recording system and a clear correlation has been established between seismicity and mining activity. While no problems have resulted from this, there is considerable interest in obtaining more information about these events, particularly as it may relate to fracturing and failure with the Dawson Bay limestones.

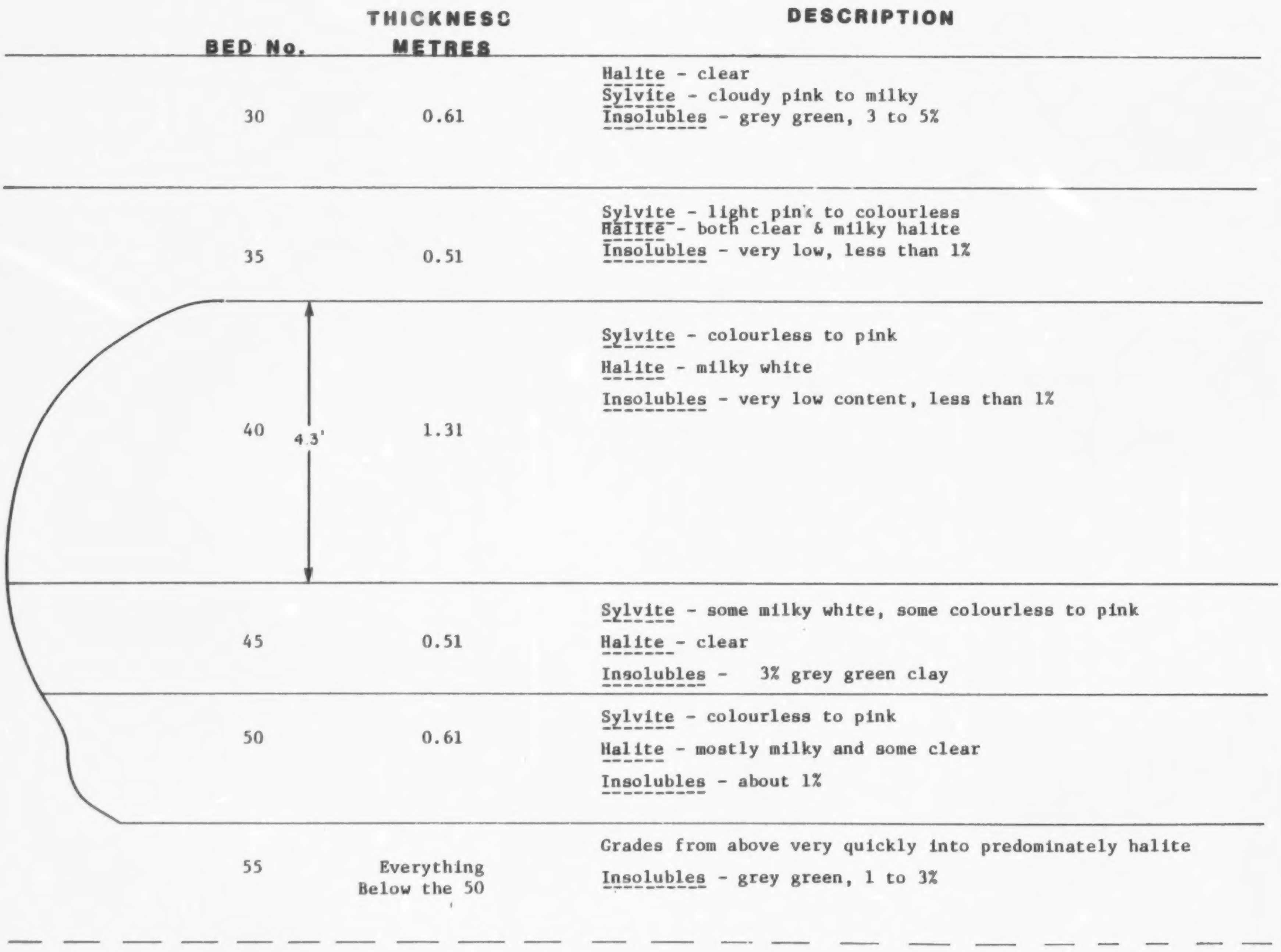
3.3 SASKATCHEWAN (ESTERHAZY)

331 GEOLOGICAL ASPECTS

The Prairie Evaporites are approximately 140 m thick in the vicinity of K-2 mine. There are three major potassium rich members within the Prairie Evaporites formation separated by beds of halite. The Esterhazy member is the lowest of these three members and is about 9 to 12 m thick. Only 2.4 m of this is economical to mine. The geological section is shown on Figure 3-7. The average grade varies between 15 and 30% K_2O.

Forty exploration wells have been drilled on the IMC property. Cores have taken in the Prairie Evaporites, examined and analyzed. Surface geophysical work has been performed though not recently. Underground geophysical work is done every five years to check the salt back thickness above the mining zone. Salt back thicknesses varying from 27 metres to 45 metres have been recorded.

I.M.C. has established a "unitized area" for tax and royalty payment purposes. This area consisting of over 148,000 acres is either owned by I.M.C., leased or subleased. Twenty thousand acres have been mined and another 80,000 acres are considered mineable from the



BED No.	THICKNESS METRES	DESCRIPTION
30	0.61	Halite - clear Sylvite - cloudy pink to milky Insolubles - grey green, 3 to 5%
35	0.51	Sylvite - light pink to colourless Halite - both clear & milky halite Insolubles - very low, less than 1%
40	1.31	Sylvite - colourless to pink Halite - milky white Insolubles - very low content, less than 1%
45	0.51	Sylvite - some milky white, some colourless to pink Halite - clear Insolubles - 3% grey green clay
50	0.61	Sylvite - colourless to pink Halite - mostly milky and some clear Insolubles - about 1%
55	Everything Below the 50	Grades from above very quickly into predominately halite Insolubles - grey green, 1 to 3%

FIGURE 3-7 GEOLOGY - MINED SECTION - K2 MINE

present shafts. The reserves are considered proven by the number of surface exploration holes that have been drilled within the area.

Insolubles in the potash zone are fairly consistent and are comprised largely of dolomitic - rich clay. The uniformity of the insoluble concentration is such that a "marker bed" is used for elevation guidance in mining.

"Washouts" or "natural caverns" have not occurred but salt horses do occur; however, they have had little effect on the overall mining plan.

332 MINING ASPECTS

To describe in some detail the mining aspects of the Esterhazy district it as decided to choose only one mine as it was believed one mine would be representative of the area. The K-2 mine of International Minerals & Chemical Corporation (Canada) Limited (I.M.C.) was chosen to represent this district.

The method of mining is by longitudinal room and pillar retreat mining. In a typical mining block, the block is developed to the boundaries and then mined back towards the main entry. A typical mining block as shown in Figure 3-8 is 2134 m wide by 4267 m long with four mining panels. A panel is 975 m by 1980 m with rooms that are 18.6 m wide and 915 m long.

The continuous miners are two-rotor Mariettas with Joy extensible conveyors. A cross-conveyor is used to place potash on the extensible conveyor when cutting passes in the room. Shuttle cars and loaders are used when cutting cross-cuts as the extensible conveyor cannot turn corners.

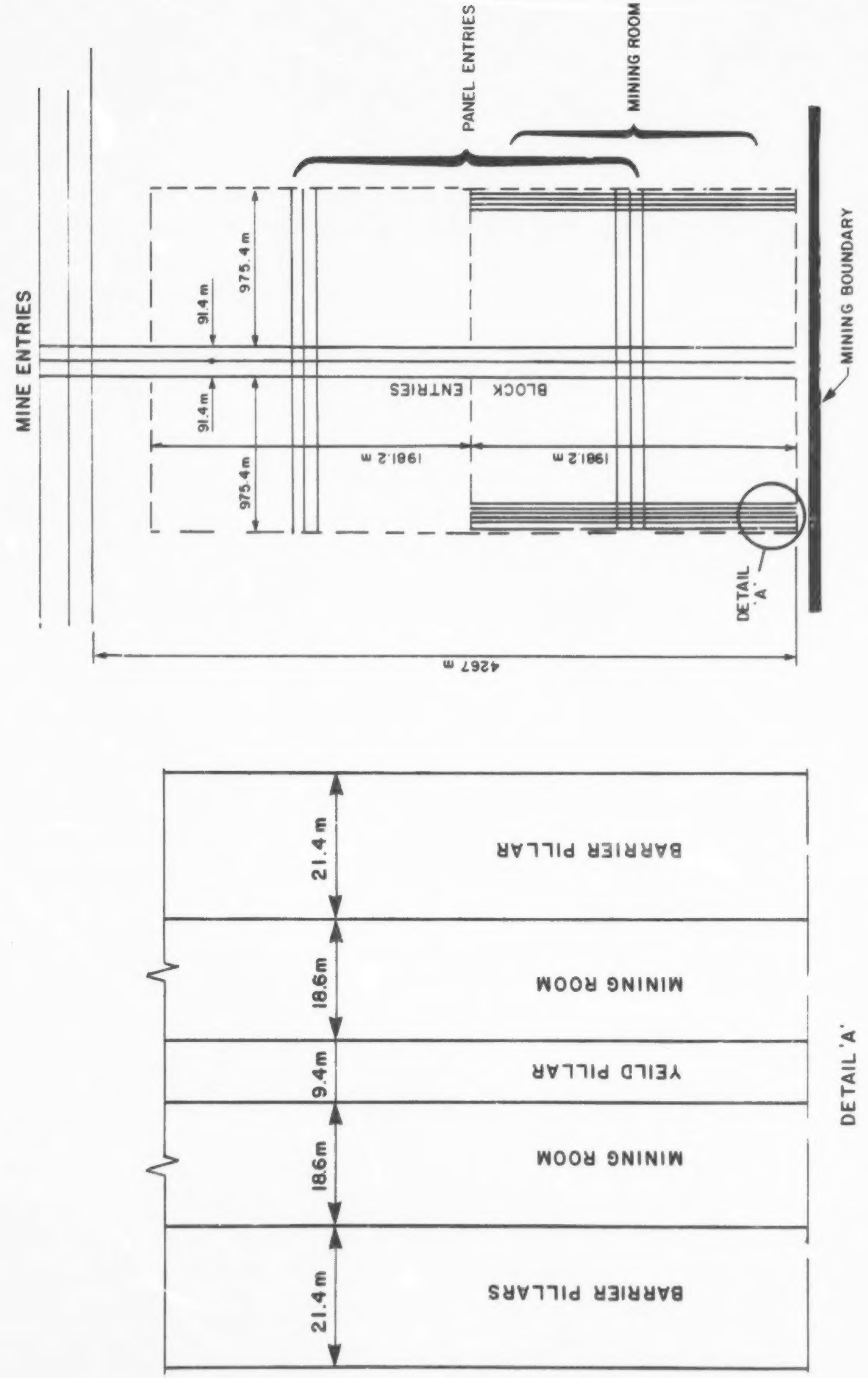

MINE ENTRIES
PANEL ENTRIES
MINING ROOM
975.4 m
91.4 m
91.4 m
975.4 m
BLOCK ENTRIES
1981.2 m
1981.2 m
MINING BOUNDARY
DETAIL 'A'
4267 m
BARRIER PILLAR
21.4 m
MINING ROOM
18.6m
YEILD PILLAR
9.4m
MINING ROOM
18.6m
BARRIER PILLARS
21.4 m
DETAIL 'A'

FIGURE 3-8 TYPICAL MINING BLOCK ESTERHAZY AREA (LONG ROOM & PILLAR)

The miner will cut an entry 2.4 m high and 4.1 m wide. For calculation purposes 4 m wide is used for the first cut and 2.4 m for subsequent passes.

A crew of two is used for extending the extensible conveyor. In mining a room or entry a 33.5 m cut is made consisting of three passes, then more belt is added. Sixty-seven to 76 metres of belt is added during each extension.

When the advance method of mining was changed to a retreat method the following conveyors were added to improve productivity:

1220 mm conveyor belts - 8.9 km.
1066 mm conveyor belts - 8.0 km.
914 mm conveyor belts - 7.2 km.

The panel conveyors are normally 1066 mm wide for two continuous miners. One panel is using 914 mm wide conveyor belt but it has only one miner to deposit the ore onto the belt.

The 1220 mm mainline conveyor is attached to the back by bolts - two bolts for every linear three metres of conveyor. The main drives are now also supported by roof bolts to the back. This allows easier clean-up than when mounted on the floor. The 1220 mm wide mainline belt is 1830 metres and is driven by three - 200 hp motors. A fourth 200 hp can be added if required. Gravity take-ups are employed on the mainline conveyors. Hydraulic take-ups are used on panel and extensible belts.

The 1220 mm mainline conveyor feeds the potash into a nominal 125 mm rolls crusher and in turn the crushed potash ore is deposited into one of the three 5.5 m diameter silos which in total can store 3630 tonnes. Underneath the silos, pan feeders deliver potash to a conveyor belt that feeds the loading pocket. The conveyors run horizontally under the silos then raise the ore at 15 degrees to the loading pockets. Each skip holds 24.5 t and is hoisted to the surface by a Koepe hoist. Wire ropes in the shaft are used to guide the skips. The Koepe hoist system is rated at 907 t per hour. Surface raw ore storage is 9072 tonnes.

The cage for moving men and small supplies travels a 6.1 m/s but is capable of 7.1 m/s.

The K-2 mine has eight continuous miners - 780 A Mariettas with two rotors. A 210 KW motor runs the rotors, a 112 KW motor is used to operate the hydraulic pump and a 15 KW motor run the exhaust fan. Each miner weighs 68 t. Availability of the continuous miner is 80 percent. Miners are rebuilt in the underground shops and each rebuild takes two months.

All underground equipment are sequenced into a regular preventative maintenance program, which is performed on the continuous miners once a day and mancarriers once a month.

The present ventilation system supplies 127.4 cubic metres per second of air to the underground workings. This amount is close to the shaft's associated cooling and heating capacity. The ambient temperature is 27°C with humidity ranging from 30 to 50 percent.

The K-2 underground operation employs approximately 120 production, 65 maintenance and 20 shaft personnel. The mine operates on a seven day week 24 hour day schedule. Eight hours every Thursday is used to perform maintenance, thus production is stopped. During the summer there is a two or three week shutdown to enable maintenance on equipment to be performed.

The old system involved shuttlecar loader haulage to the panel or main conveyor belts, used a 'checker board' room and pillar system, and did not follow a retreat mining pattern. The new mining system using extensible conveyors involving long rooms, yield and barrier pillars on a retreat pattern was introduced to increase productivity and lower costs; to increase extraction; and to improve ground conditions in the mining area. As a result of introducing this new system manpower requirements are less at each mining machine; extraction rates have increased and retreat mining has reduced the risk of accidents due to falls of ground.

I.M.C. state that they have not experienced any major problems which would require the development of a new mining method. The underground operations are presently capable of producing all the hoisting operation can handle. Any improvements or modifications which would be considered would have to be cost effective or improve the operating conditions.

The above statement, of course, does not comment on the merits of increasing recovery with respect to their present practice. Their present recovery is 54 percent for a panel and slightly over 40 percent for a block.

333 GEOTECHNICAL ASPECTS

The formation is nearly horizontal and the potash seam is overlain by approximately 30 metres of evaporites. These evaporites form an impermeable barrier between the overlying Dawson Bay limestone and the potash seam being worked.

The Dawson Bay limestone is generally dry and salt filled, but when salt filling is absent it can contain large volumes of water. It is considered a high risk operation to drill through the salt back in the mine to explore the Dawson Bay and, therefore, the characteristics at a particular mine are not well known.

The thick salt formation in the roof results in stable mining conditions and unsupported rooms up to 26 m wide have been mined in the area.

One of the mines in the Esterhazy district commenced mining with a regular rectangular room and pillar layout using an advance mining sequence. The width of the rooms were 6.4 m wide and the widths of the pillars were around 17 m. The percentage extraction of the mining panel was around 35 percent using the advance mining sequence.

As a result of investigations to improve stability, mining has changed to a retreat sequence with two mining rooms 18.6 m wide separated by a yield pillar 9.4 metres wide and with barrier pillars on either side 21.4 m wide. Figure 3-8 illustrates this. This results in an extraction ratio in the mining panel of 55 percent and an overall extraction ratio of 40 percent.

While ground conditions are reasonably good, the change to retreat mining and reduction in extraction in carnallite zones was initiated because of stability problems. Roof slabbing is experienced in some areas and rock bolts and timber cribs are used in problem areas. Convergence in the wide rooms is typically 100 to 170 mm in the first year settling down to a long term creep rate of approximately 25 mm per year.

One of the mines in the Esterhazy area is presently investigating total extraction mining in which the void will be progressively backfilled with salt tailings. Under this system it is expected that the presence of the thick salt roof and the limited convergence due to the backfill will prevent groundwater flows from the Dawson Bay to the mine workings.

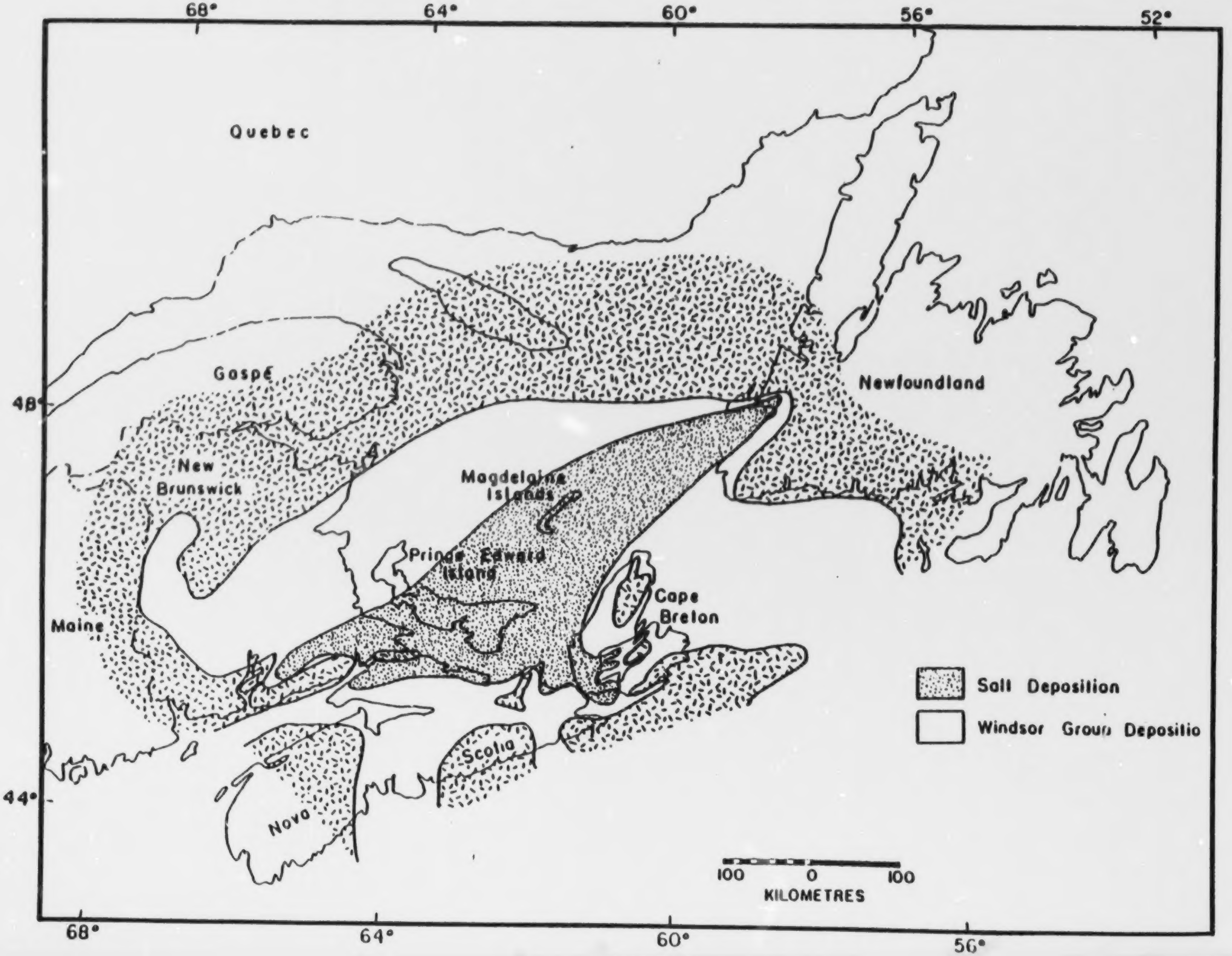
3.4 NEW BRUNSWICK

341 GEOLOGICAL ASPECTS

Mississippian Windsor Group salt deposits of the Maritime provinces are contained in a series of linear subbasins having northeast-southwest orientations. The structural configuration of the subbasins is the result of disturbance of the major Fundy Basin which extends across all of Atlantic Canada. Extensive exploration to date has confirmed commercial potash zones in the Moncton subbasin of southern New Brunswick. The sub-basin (Fig 3-9) is fault bounded to the north and south and three structures at the southwest end of the trend have received the most attention for immediate development: the Dunsinane Synclinorium (Penobsquis, Plumwesepp, or Sussex; controlled by PCA), the Marchbank Syncline (Clover Hill or Salt Springs, a Denison property), and the Case Syncline (Millstream locale, held by BP Exploration). Each property has distinct geological features, particularly in terms of structural controls (Fig 3-10).

The Penobsquis property is underlain by a domal structure having an east-west orientation. The single main potash seam occurs at about 500 metres in depth and is between 5 and 36 metres in thickness. It dips to the north and south, away from the domal axis, at angles of approximately 45°. Ore grades are between 24 and 25 percent K_2O. Production is presently being established on the north limb of the structure where only sylvinitic ores have thus far been encountered.

FIGURE 3-9 REGIONAL GEOLOGY - NEW BRUNSWICK


68°
64°
60°
56°
52°
48°
44°
Quebec
Gaspé
New Brunswick
Maine
Newfoundland
Magdelaine Islands
Prince Edward Island
Cape Breton
Nova
Scotia
Salt Deposition
Windsor Group Depositio
100
0
100
KILOMETRES

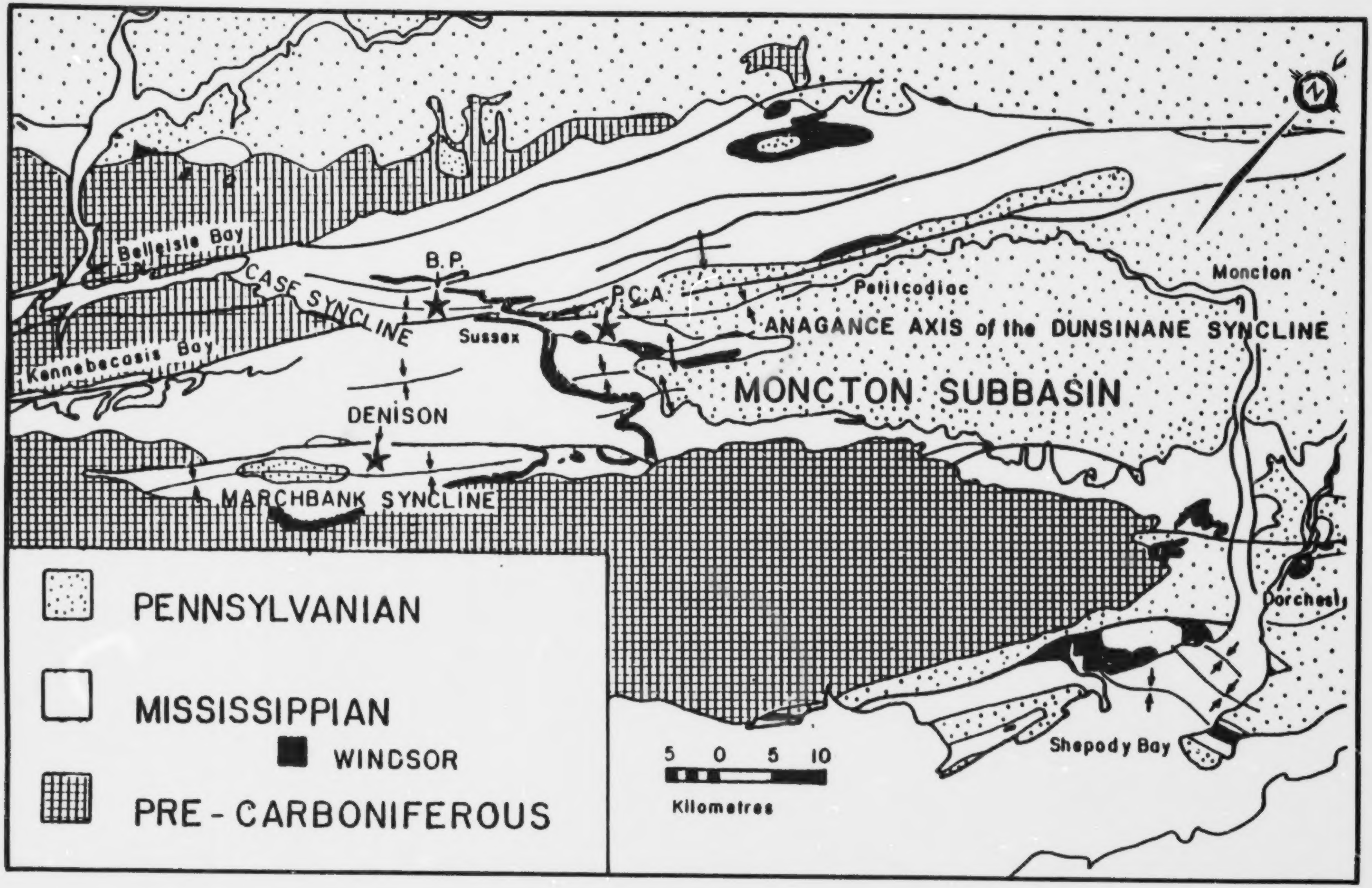

Bellelsle Bay
Kennebecasis Bay
CASE SYNCLINE
B.P.
Sussex
P.C.A.
Petitcodiac
Moncton
ANAGANCE AXIS of the DUNSINANE SYNCLINE
MONCTON SUBBASIN
DENISON
MARCHBANK SYNCLINE
Dorchest
Shepody Bay
N
5 0 5 10
Kilometres
PENNSYLVANIAN
MISSISSIPPIAN
WINDSOR
PRE - CARBONIFEROUS

FIGURE 3-10 GEOLOGY OF SOUTH-EASTERN NEW BRUNSWICK

(★ Potash Deposits)

Carnallitic sections have been intersected by drilling on the southern flank (Fig 3-11).

A barren salt body approximately 600 metres long has been penetrated in the initial underground openings. Salt back thicknesses average about 30 metres.

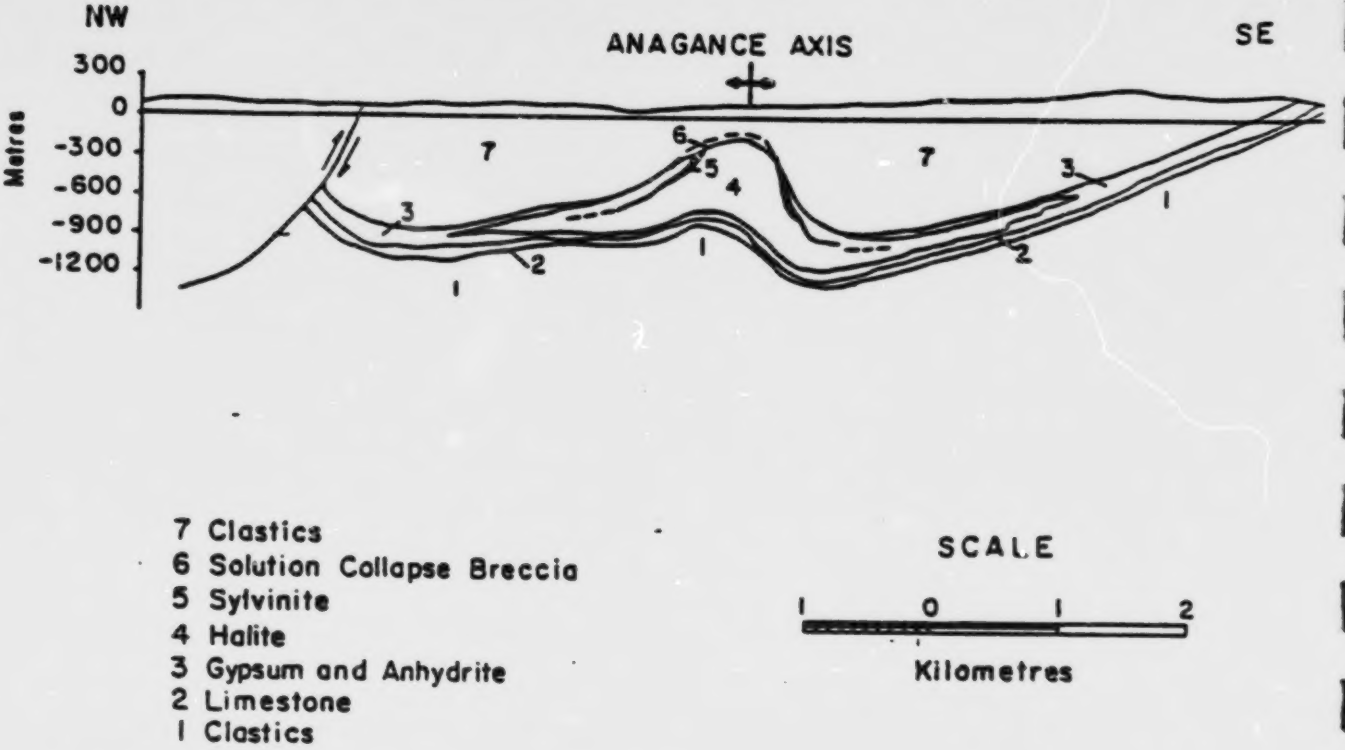
Exploration to date has proven up to 30 years of reserves assuming an annual mine production rate of 1.9 million tonnes of ore or 0.635 million tonnes of product.

At Clover Hill a single potash seam is present which is relatively flat to moderately undulating in the southern sector of the deposit. Truncation of the potash has taken place in part, following post-depositional erosion of the salt. The principal sylvinite bed occurs at a depth of about 800 metres and varies in thickness from 1 to 25 metres. Thickness changes are noted to be in association with local structural controls. Ore grades vary between 24 and 35 percent K_2O with some local interruptions by barren salt bodies.

Proven reserves have been established to be 41 million tonnes, more than sufficient for five years of production at initial development and processing capacities. Probable and proven reserves total 160.8 million tonnes with an average grade of 28.5 percent K_2O. The total in-situ reserves for the Marchbank Syncline, including those of the more structurally complex area to the north, are estimated to be about 230 million tonnes with an average grade of 28 percent K_2O.

Published information on the Millstream deposit is very limited. Exploration to date has reportedly confirmed the presence of a multiple succession of sylvinitic zones (up to 5) and richly carnallitic beds are also present (3). The potash occurs at depths between 700 and 1100 metres. Individual zones may be up to 35 metres thick. The

A. PLUMWESEEP SALT/POTASH DEPOSIT


NW
ANAGANCE AXIS
SE
300
0
-300
-600
-900
-1200
Metres
7
6
5
4
3
2
1
7 Clastics
6 Solution Collapse Breccia
5 Sylvinite
4 Halite
3 Gypsum and Anhydrite
2 Limestone
1 Clastics
SCALE
1 0 1 2
Kilometres

B. SALT SPRINGS SALT/POTASH DEPOSIT

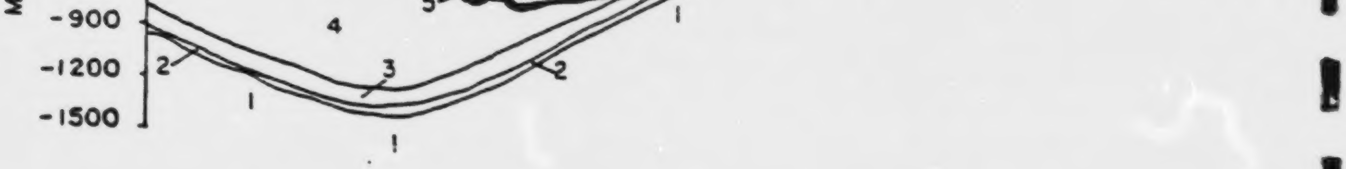

NW
MARCHBANK SYNCLINE
SE
300
0
-300
-600
-900
-1200
-1500
Metres
7
6
5
4
3
2
1

FIGURE 3-11 GEOLOGICAL CROSS SECTIONS OF THE PLUMESWEEP AND SALT SPRINGS SALT/POTASH DEPOSITS

beds are gently to steeply undulating and dips are apparently only influenced by broad flexures within the regional structure which has an east-west oriented axis with a gentle westerly plunge. (Fig 3-12).

342 MINING ASPECTS

As has been indicated in the previous section, the geology of the potash zones in New Brunswick is somewhat different to that of the Saskatchewan potash deposits. This factor, taken with the requirement of the N.B. Department of Natural Resources that disallows the dumping of salt tailings on the surface, has led to the evolvement of vastly different methods of mining.

In briefly describing these methods, it should be borne in mind that of the three properties under development, only one has reached the production stage and hence is initiating its chosen system, whilst, for the other two mines, the chosen mining system is still untried.

All three systems proposed involve some form of mining with backfill, ranging from cut and fill stoping in the steep variable thickness bed at Penobsquis, through, in the initial moderately dipping bed at Saltsprings, a form of long room and pillar mining with backfill (and possible open stoping, with backfill in the future steeper parts of the deposit) to a mixture of chamber mining with backfill in the medium gradient areas and cut and fill stopes in the steeper gradient areas at Millstream.

A brief summary of each mining system is given below.

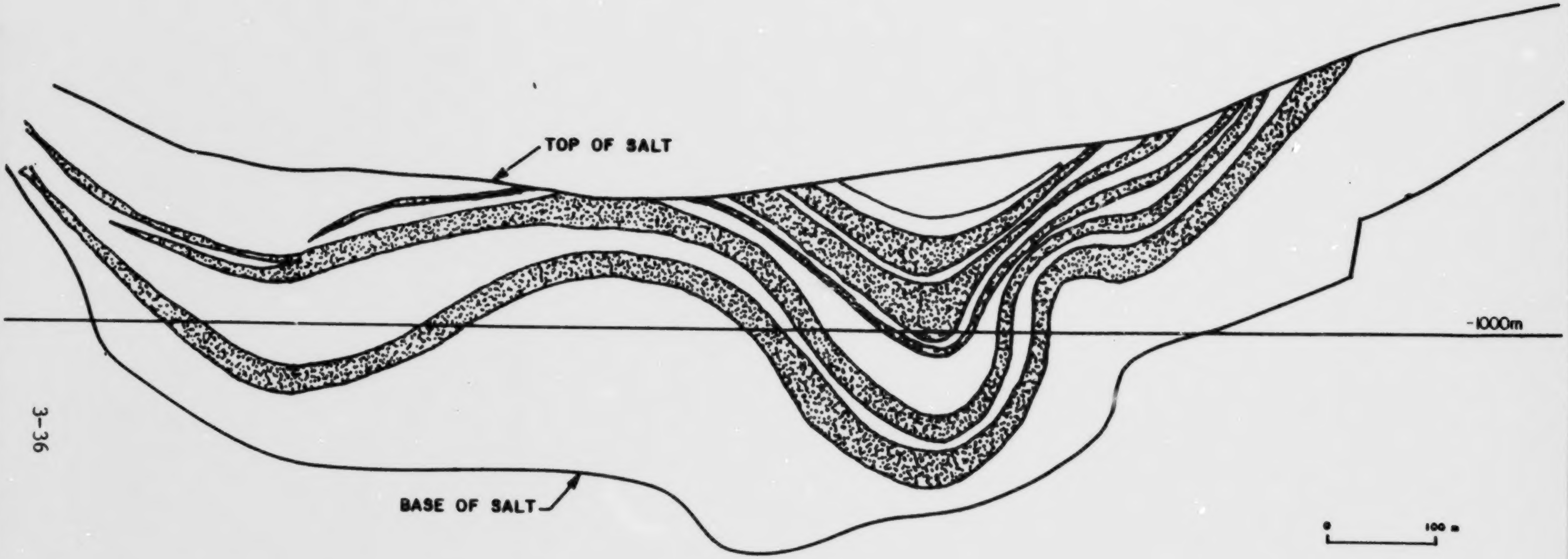

TOP OF SALT
-1000m
BASE OF SALT
0
100 m

FIGURE 3-12 SECTION THROUGH MILLSTEAM POTASH DEPOSITS

Penobsquis Mine (Potash Company of America)

The cut and fill system is applied to the upper part of the north limb of the potash bed which varies in thickness from 6 m to 37 m and in gradient from 45° to vertical. The cut and fill system will be worked between sub-levels 120 m apart, with an expected strike panel length of 600 m. The width of the stope will be the seam thickness (Figure 3-13).

The potash ore will be mined using the Alpine 100-33 continuous miners (or roadheaders). These machines are capable of cutting 11.6 m wide and 6.7 m high in a single pass. The first cut at the base of the panel will be 6.7 m high, the Alpine discharging via a series of 30 m portable bridge conveyors directly onto the main belt conveyors for transport to the shaft bottom bunkers. As the miner proceeds along the 600 m length of the panel, salt tailings are sent down the shaft through a drop pipe, discharging onto a tailings belt conveyor system which carries the tailings through the mine into the stope where they are placed to a depth of 4.25 m using a 4.5 m^3 scoop tram to distribute and compact the salt. This will leave a 2.4 m space between the fill and the potash roof. On completion of the 600 m strip, the continuous miner will be reversed on top of the fill to the beginning of the panel, and a second strip commenced, the machine mining 4.25 m of potash, and again 4.25 m will be backfilled with tailings. The process will be repeated until the upper sub-level is reached and the panel mined out.

The Alpine miner is expected to produce 250 tonnes per hour and average 2700 tonnes per day for a stope productivity in excess of 200 t per manshift. Mining is expected to be continuous, by working two 12 hour shifts per day 7 days per week.

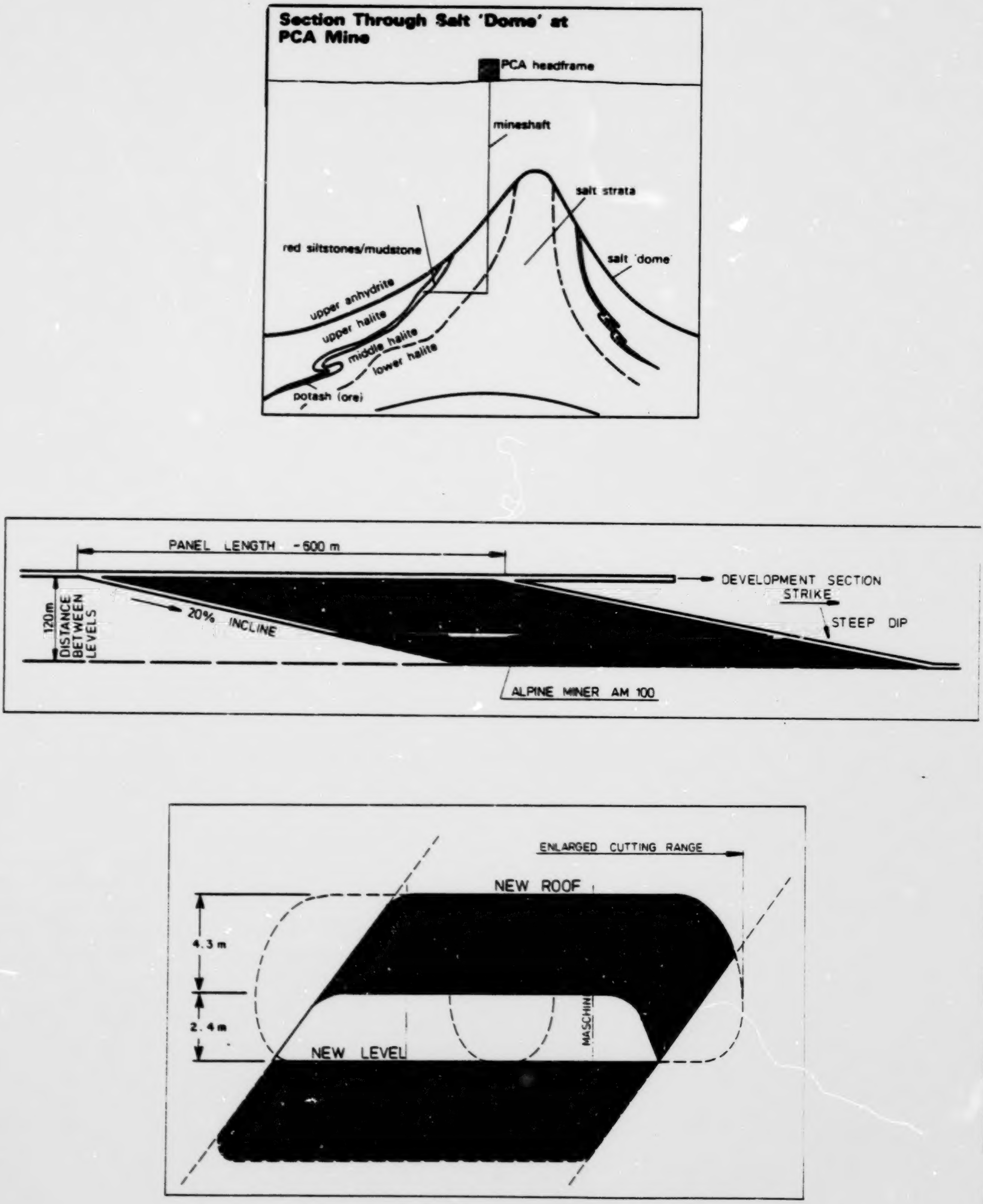

Section Through Salt 'Dome' at PCA Mine
PCA headframe
mineshaft
salt strata
red siltstones/mudstone
salt 'dome'
upper anhydrite
upper halite
middle halite
lower halite
potash (ore)
PANEL LENGTH - 600 m
DEVELOPMENT SECTION
STRIKE
STEEP DIP
120m
DISTANCE BETWEEN LEVELS
20% INCLINE
ALPINE MINER AM 100
ENLARGED CUTTING RANGE
NEW ROOF
4.3 m
2.4 m
NEW LEVEL
MASCHINE

FIGURE 3-13 CUT & FILL STOPING - PENOBSQUIS MINE

Saltsprings Mine (Denison - Potacan)

The mining methods expected to be used at this mine reflect the varying gradient of the deposit, its thickness and the thickness of the salt back.

In the early years, the area to be mined is relatively consistent dipping at between 12° and 20° with the salt back thickness increasing as the seam depth increases. No mining will be carried out where the salt back is less than 10 metres. Between 10 and 40 metres of salt back cover, partial extraction by a modified form of chamber and pillar mining will be practised. Room widths will not be greater in dimension than the thickness of the salt cover, to give approximately 30% recovery.

Beyond the 40 m salt back cover, mining is expected to be by long rooms, approximately 200 m by 42 m. Marietta Miners will mine the top lift and depending on the bed thickness which ranges from 6 m to 30 m, successive lifts will be mined on the retreat, either by the miner, or by drill and blast methods. The roof will be supported by rock bolts when the top lift is cut, and the room will be backfilled with salt tailings when mining is completed. Recovery is expected to be between 60 and 65% in the long room mining section.

At the end of the permit area, expected to be mined in the future, the potash beds fold and become very steep (almost vertical). It is anticipated that some form of cut and fill stoping will be used to mine these areas.

Millstream Project (B.P.)

This project is at the stage where exploration is being undertaken by drillholes from the surface. These have identified some five potash beds varying in thickness from 3.7 m to 38 m and at gradients ranging from flat to vertical due to the anticlinal/synclinal nature of the deposit. At present, mining methods have only been looked at conceptually. These suggest that some form of long chamber mining with backfill will be used to obtain a 40% recovery. In the steeper sections, cut and fill stoping is likely. Workings in each seam will be so laid out that pillars in each seam will be vertically in line with each other. In the chamber mining, it is anticipated that the bottom lift will be mined by continuous miners, with the chambers being enlarged upwards using drill/blast methods. Chamber dimensions are expected to be 450 m long by 24 m wide and height to the thickness of the seam or sub-level. Pillar widths will be 36 m.

343 GEOTECHNICAL ASPECTS

There is presently one mine in New Brunswick which has recently commenced production of potash and one that is about to commence. Very little geotechnical information is available on the mine that is about to commence production. It is understood that it is a regionally flat lying deposit and it is known that significant aquifers overly the ore zone. The deposit is approximately 600 to 1000 m below surface and the mining horizon is overlain by a sequence of evaporites of variable thickness (10 to 60 m). The potash seam to be mined varies from approximately 2 to 10 m in thickness. Further details of the immediate roof strata and expected behaviour were not available.

The mine that has recently commenced commercial production is using a cut and fill mining system to mine the potash. The depth of mining during the early development will range between 400 and 700 m. The most important characteristics of the deposit from a geotechnical viewpoint are the dip of the orebody of 45 degrees in the mining area, and the thick sequence of uniform salt overlying the seam (minimum thickness 30 m). Prominent clay layers or other weakness planes are not evident in the immediate hanging wall and likewise the salt in the footwall is massive and competent. No major aquifers overlie the mining seam. The expected extraction in the mining panels is 80 percent or more and the overall extraction is expected to be approximately 60 percent.

No geotechnical problems have been encountered in the mine, although it is in the very early stages of development (stoping in the potash had not commenced at the time of the visit to the mine). The deposit appears to be well suited to cut and fill mining. The deposit is typically 16 m wide and stable back conditions are expected over the width in the potash. Similarly the exposed footwall and hangingwall in the stope are expected to be reasonably competent.

Regional stability is also unlikely to pose a problem. The 30 m or more thickness of salt in the hangingwall will deform plastically to compress the fill but major fracturing or disruption of this unit is not anticipated.

Stability problems may be encountered as deeper stopes are mined up towards overlying mined and filled areas. The stress in the resulting sill pillar will increase as extraction increases and significant yielding of the pillar may develop in extreme situations. Mining is likely to cease before these conditions are reached, however, and it is not believed that the ore remaining in the final sill pillar will have a significant adverse impact on extraction.

It has been found in hard rock mines using cut and fill methods to mine inclined orebodies, and it is likely to be equally true for the cut and fill mining of this potash deposit in New Brunswick, that provided the fill cannot liquify, the properties of the fill are not of major importance. It provides a platform to work off and prevents massive caving of the hangingwall but does not change the stress distributions around the working openings significantly. In this context, the salt tailings will likely consititute a very satisfactory backfill material.

3.5 SOLUTION MINING

The salt beds of the Prairie Evaporate formation occur at depths of 180 and 240 m below the surface in northern Alberta. The northern edge of this formation in Saskatchewan ranges in depth from 760 to 900 m. The depth increases in a southeast direction at a rate of two to eight metres per kilometre until it reaches more than 2100 metres at the south Saskatchewan border.

The deepest conventional room and pillar mine is around 1075 m and it is believed that conventional mining will not extend much beyond this figure. Therefore, a great portion of the potash reserves of Saskatchewan will have to be mined by solution mining if the potash is to be recovered.

Rock salt has been successfully solution mined in many countries over the years however, many attempts have been made to produce potash by the same method but only two companies have been successful: Kalium Chemicals Ltd. and the Cane Creek Mine of Texas Gulf. Kalium Chemicals Ltd. differs from Cane Creek as the latter was formerly a conventional room and pillar mine.

There are significant differences in solution mining of rock salt and potash solution methods. Rock salt is usually relatively pure and is found in thick beds, while potash tends to be located in relatively thin bedded formations and contains certain amounts of other soluble minerals. In comparison to rock salt, much less potash is dissolved in the same quantity of water circulated therefore, the amount of water required to be evaporated for potash is greater than that for rock salt.

The companies mining by solution methods have released very little technical information about their techniques. The following information has been gleaned from literature research and patents.

The extraction of potassium chloride is the object of solution mining of a potash deposit. This can be done in two ways: dissolve the potassium chloride selectively leaving sodium chloride underground or dissolve both potassium chloride and sodium chloride. There are two ways to dissolve the salts; isothermally or polythermally.

The dissolution method of selectively dissolving potash by isothermal techniques involves using a saturated sodium-chloride solution as a solvent. This solution will dissolve potassium chloride by replacement of sodium chloride, without any temperature change; thus, the solution will selectively remove potassium chloride in an underground cavity. When the solution is saturated both with sodium chloride and potassium chloride, the solution can be pumped from the cavity and potassium chloride can be removed from the solution in the process plant. The disadvantage of this method is that the dissolving of potassium chloride occurs very slowly by partial replacement of the sodium chloride in the solution. This process is usually eliminated from consideration because the process is too slow and, in addition, the precipitating sodium chloride will tend to blanket the surface of the dissolving potash and further slow the dissolution of potash.

In the polythermal method the solubility of potassium chloride increases with a rise in temperature while sodium chloride solubility is only increased slightly. Thus a solution which is saturated with both sodium chloride and potassium chloride at a low temperature will, upon raising the temperature, be saturated with sodium chloride but unsaturated with potassium chloride. Thus the heated solution will selectively dissolve the potassium chloride. The solution can then be brought to surface and the potassium chloride removed by cooling. This avoids evaporation but the liquor must be reheated before being sent back into the underground cavity. The problem with this method is that the solvent will not "honeycomb" the deposit and the dissolution process will slow up as rock salt will bar or bury some of the potash thus diminishing contact with the potash salts.

The best method is to dissolve both the potassium chloride and sodium chloride in the salt deposit. An unsaturated brine or fresh water can be used as a solvent. In an unsaturated brine solution the mixture of the brine should be adjusted so that the solution will dissolve potassium chloride and sodium chloride in the same proportion as they are found in the underground deposit. The saturated, or as is usually the case, the 95 percent saturated solution is pumped up from the cavity and the crystallization process recovers the potassium chloride and sodium chloride.

In Saskatchewan, the potash mineralization is found in three or more relatively continuous and consistent beds. This continuity of the beds plus the uniformity and flatness along with a high average grade and good thickness are decided advantages for solution mining. The first step in the mining process is to develop a sump in the rock-salt strata below the potash zone. To do this a well is drilled into the evaporite formation below the potash bed and two concentric tubes are installed. A hot unsaturated brine or fresh water is pumped down the well accompanied by a fluid which is immiscible and inert. This second fluid, usually a light hydrocarbon, although it could also be air, nitrogen or light inert gas floats to the roof of the cavity and prevents the roof from being dissolved. The cavity then expands to the sides and the bottom with the minimum acceptable diameter being about five metres. The solution which has been dissolving the sodium chloride becomes denser, sinks and then is pumped to surface, Figure 3-14. Once the cavity has expanded to an acceptable size, the flow of the immiscible fluid is reduced or stopped and roof which contains the sylvinite, a mixture of sylvite and halite, is dissolved and the solution is pumped to the surface where the potash is recovered.

The retention time of the the brine in the cavity varies greatly with mining conditions, the dimensions of the cavity and the flow rate of the solution. When cavities increase to a diameter greater than 100 m, it is possible to reduce the amount of sodium chloride being extracted by increasing the saturation point of sodium chloride in the brine solution.

It is desirable that two cased wells be connected underground as this allows a greater flow throughout the cavities and thus increases production.

When the present conventional room and pillar mines have extracted all the potash that can be safely removed, it is envisaged that the remaining potash will be extracted by solution methods.

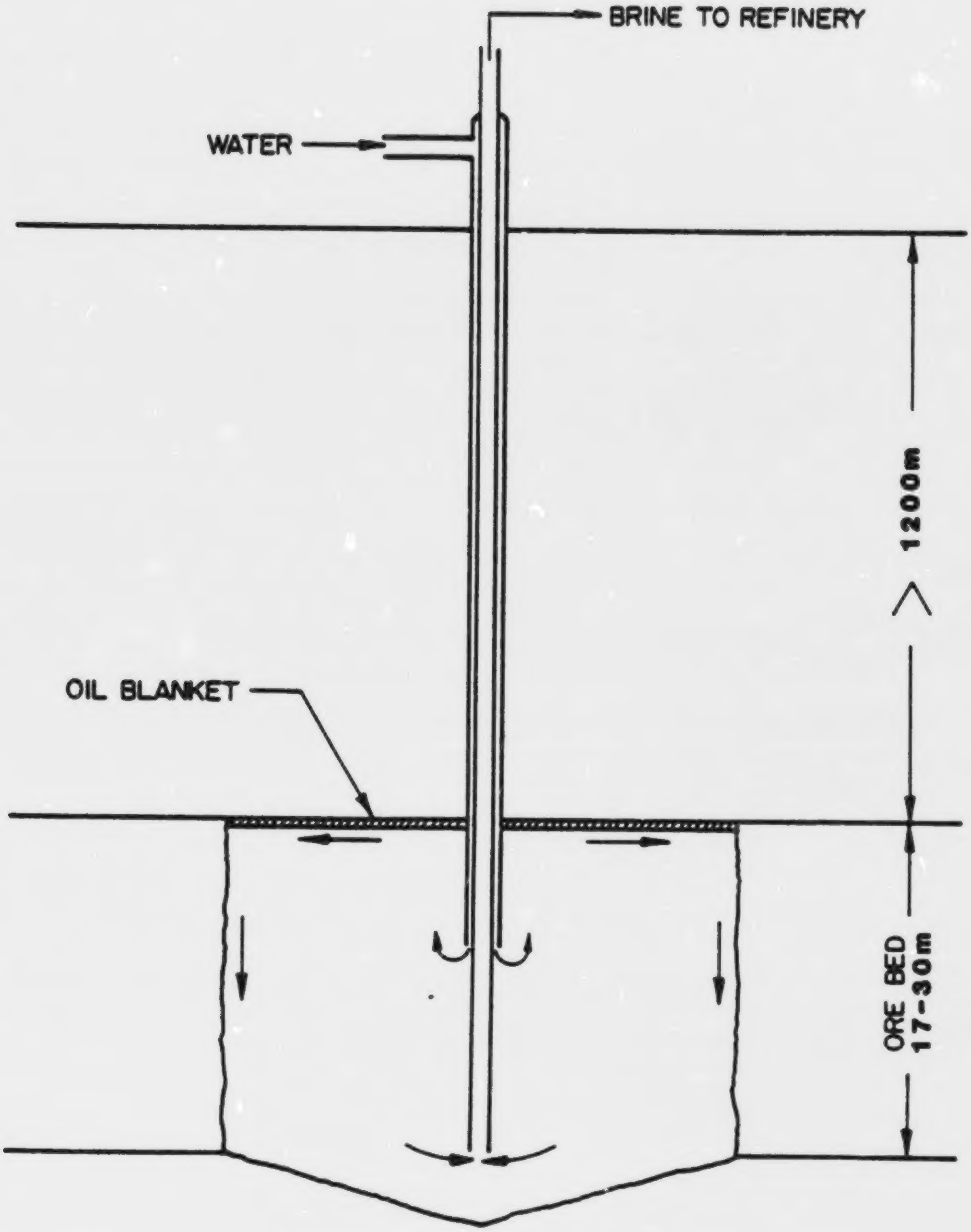

BRINE TO REFINERY
WATER
OIL BLANKET
>1200m
ORE BED
17-30m

FIGURE 3-14 DIAGRAM SHOWING BASIC PRINCIPLES OF SOLUTION MINING

PART 4

INTERNATIONAL MINING METHODS

PART 4 - INTERNATIONAL MINING METHODS

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4.1 U.S.A. - NEW MEXICO

411 GEOLOGICAL ASPECTS

Two significant Permian evaporite basins have been defined in western Texas and southeastern New Mexico. The earlier Midland Basin was isolated as a back reef environment by the Capitan barrier reef during Guadalupian time (Figure 4-1). Commercial potash deposits have not been isolated to date in this feature.

A subsequent barrier and resultant basinal restriction along the so-called Diablo Platform to the southwest led to continued evaporite deposition across both the Midland Basin and the newly developed Delaware Basin (the latter part of which occurred in closer proximity to the open sea conditions). The Central Basin Platform between the two basins served to isolate most of the potash deposition to the Delaware Basin.

All commercial beds of potash in the region are contained within the McNutt potash zone of the Salado Formation in the Carlsbad area of southeastern New Mexico. The Salado (Figure 4-2), a unit of the Ochoa evaporite series, varies between 400 and 700 metres in thickness and the McNutt zone occurs near the middle of the formation. Eleven ore zones have been identified within the McNutt over a 50 to 140 metre stratigraphic thickness. Six of the eleven ore zones have been exploited in the Carlsbad district (1, 3, 4, 5, 7, and 10) and of these the lowermost, or First ore zone, has been most extensively mined (Figure 4-3).

Two types of potash deposits are present in the area: polyhalite and sylvite deposits. The polyhalite deposits are calcium-rich and potash occurs in the form of the complex triple sulfate polyhalite.

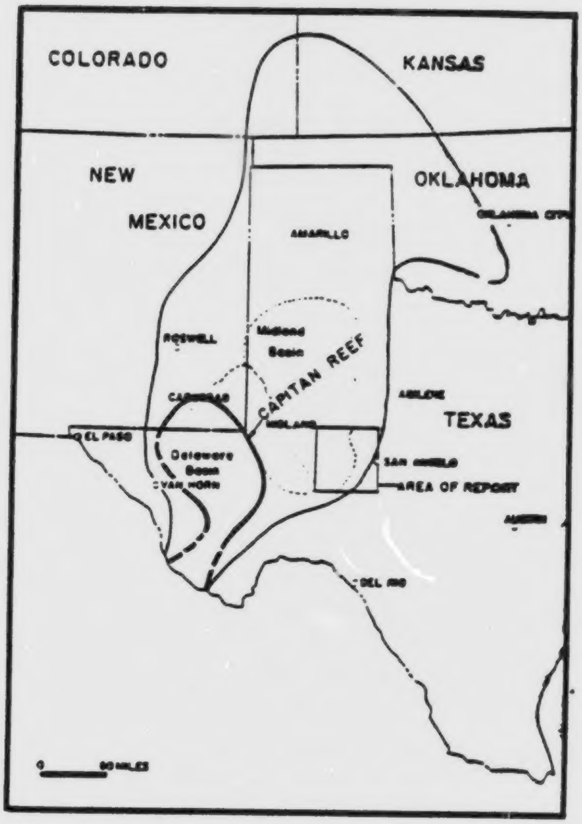

COLORADO
KANSAS
NEW MEXICO
OKLAHOMA
OKLAHOMA CITY
AMARILLO
ROSWELL
Midland Basin
CAPITAN REEF
CARLSBAD
MIDLAND
ABILENE
TEXAS
EL PASO
Delaware Basin
VAN HORN
SAN ANGELO
AREA OF REPORT
AUSTIN
DEL RIO
0 80 MILES

FIGURE 4-1 REGIONAL GEOLOGY - NEW MEXICO POTASH

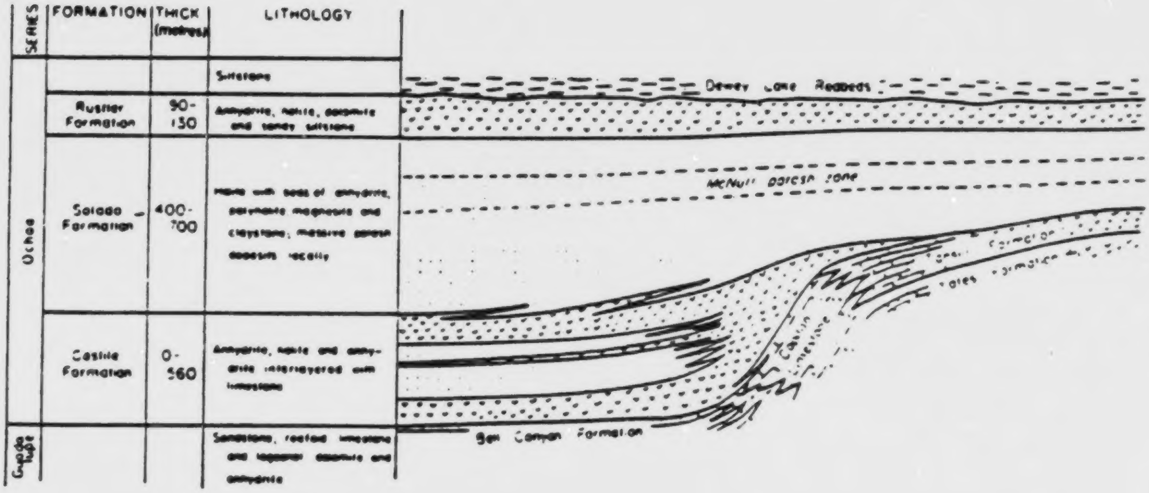
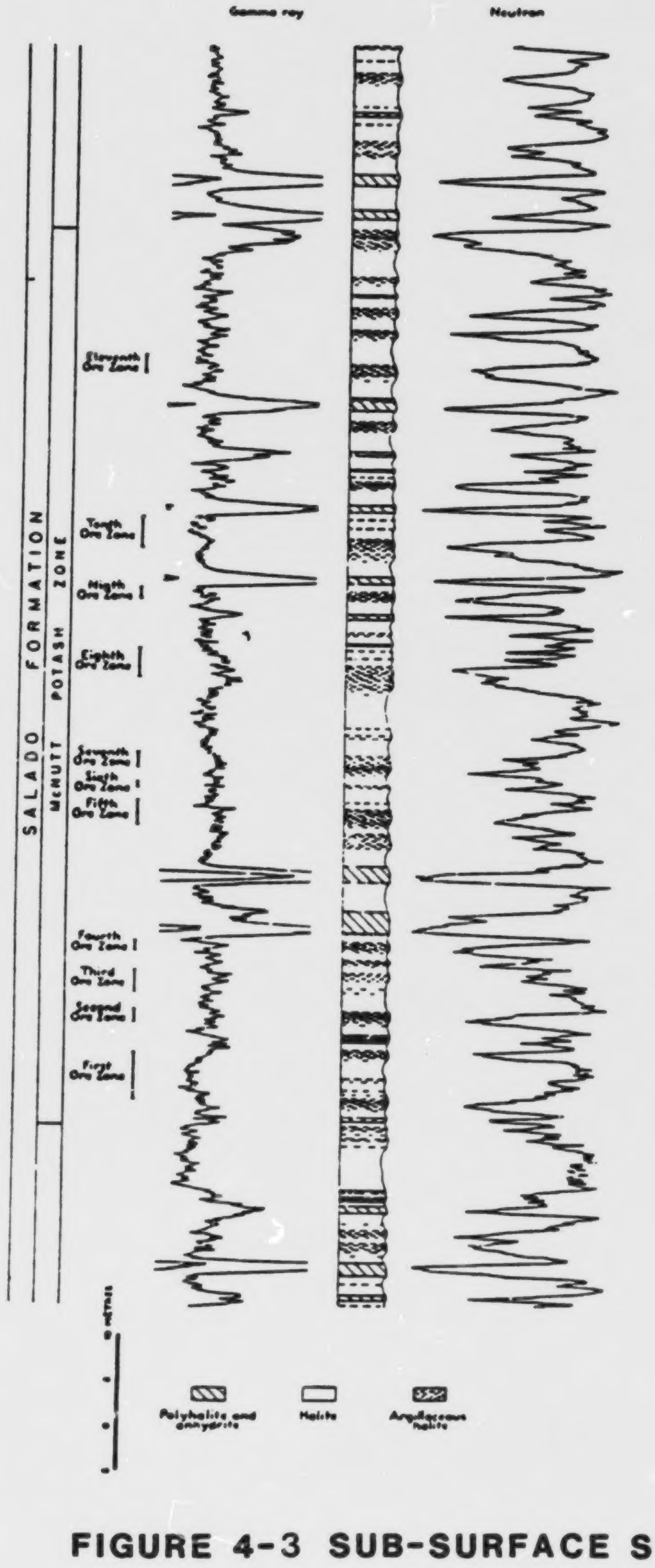

SERIES
FORMATION
THICK (metres)
LITHOLOGY
Ochoa
Guadalupe
Siltstone
Rustler Formation
90-130
Anhydrite, halite, dolomite and sandy siltstone
Salado Formation
400-700
Halite with beds of anhydrite, polyhalite magnesite and claystone; massive potash deposits locally
Castile Formation
0-560
Anhydrite, halite and anhydrite interlayered with limestone
Sandstone, reefoid limestone and lagoonal dolomite and anhydrite
Dewey Lake Redbeds
McNutt potash zone
Formation
Yates Formation
Capitan Limestone
Bell Canyon Formation

FIGURE 4-2 SCHEMATIC DIAGRAM OF OCHOA EVAPORITE FORMATIONS


Gamma ray
Neutron
SALADO FORMATION
McNUTT POTASH ZONE
Eleventh Ore Zone
Tenth Ore Zone
Ninth Ore Zone
Eighth Ore Zone
Seventh Ore Zone
Sixth Ore Zone
Fifth Ore Zone
Fourth Ore Zone
Third Ore Zone
Second Ore Zone
First Ore Zone
meters
Polyhalite and anhydrite
Halite
Argillaceous halite

not commercial

MINED { **DUVAL, IMC, NAT POTASH**
KERR McGEE, MISSISSIPPI

not commercial

not commercial (CARNALLITE)

MINED - MISSISSIPPI
not commercial
MINED - MISSISSIPPI, IMC

MINED-IMC, DUVAL (LANGBEINITE)
MINED - PCA, AMAX
not commercial

MINED - PCA, IMC, AMAX

FIGURE 4-3 SUB-SURFACE SECTION SHOWING ORE ZONES

Sylvite deposits are calcium-poor and potash is present as sylvite, langbeinite, or carnallite. Both deposits may be classified according to dimensional forms as massive, disseminated, vein, or lenticular. The massive sylvite deposits are the least numerous and most restricted in distribution. However, they are reported to be the occurrences of principal economic interest and contain all known sylvite and langbeinite in mineable amounts.

The structural setting within the mining district is relatively simple and only minor bedding undulations are noted for the most part. A Tertiary basaltic dike less than 2 metres in thickness has been encountered in two mines and presents no difficulty to mining. Solution collapse chimneys are also present and one such feature has been found in one of the mines. Apart from local destruction of the ore beds they present no unusual obstacles to mining.

Salt horses are a common phenomena in the mines of the Carlsbad district.

Sufficient salt back material is almost invariably present due to the statigraphic position of the McNutt potash zone, situated well below the top of the Salado halite strata.

412 MINING METHODS

Potash mining in the Carlsbad Basin (Figure 4-4) has been practised for more than 50 years, the first mine opening in 1931, and the most recent in 1966. Depth of mining ranges from 200 to 600 metres (Table 4-1).

All of the early mines commenced working with the conventional room and square pillar system utilizing drill and blast methods with

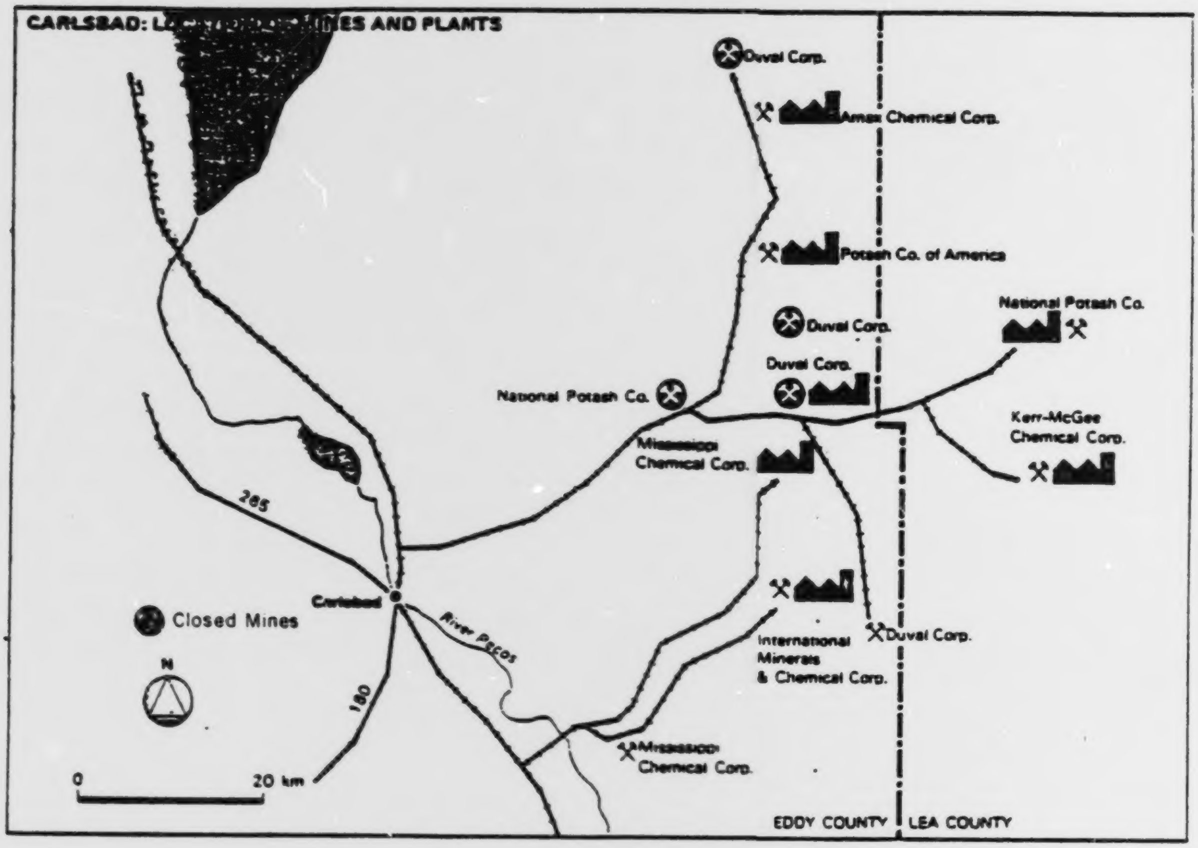

CARLSBAD: LOCATION OF MINES AND PLANTS
Duval Corp.
Amax Chemical Corp.
Potash Co. of America
National Potash Co.
Duval Corp.
Duval Corp.
National Potash Co.
Mississippi Chemical Corp.
Kerr-McGee Chemical Corp.
285
Carlsbad
Closed Mines
River Pecos
N
180
International Minerals & Chemical Corp.
Duval Corp.
Mississippi Chemical Corp.
0
20 km
EDDY COUNTY
LEA COUNTY

FIGURE 4-4 LOCATION OF POTASH MINES - NEW MEXICO

TABLE 4-1

LIST OF NEW MEXICO POTASH MINES

Mine	Potash Zone	Depth in Metres	Ore Type	Mining thick in metres	K_2O (%)	Insols. %	Reserves
Mississippi Chem. Corp. (maint. only)	7	260 - 520		1.2 - 1.8	14.5	3	
	5			0.9 - 1.5	14.5		50 years
IMC	10	215 - 270	mixed sylvinite - langb.	2 or less			(future)
	5		"				
	1		"				
PCA	3	296 - 305	sylvinite "	1.2 1.2	12.5 23		10 m tonnes
Amax Chem Corp.	3	220 - 345		1.4	11 - 12	2.25	
	1		sylvinite minor carn & polyh.	1.5	18 - 20	1	
Duval Corp.	10	274	sylvinite		16	4	
		328	langb.		8.4 (6.9% MgO)		37.7 m tonnes
National Potash Co.	7	490 - 550	sylvinite, some carn.	1.7	14	-	
Kerr-McGee	10 (lower part)	495	sylvinite	1.3	16	6	63.5 m tonnes (25 years)

mobile cutters, drilling and loading equipment and shuttlecars loading mine cars hauled by trolley locomotives. In many cases, pillar mining was practised and panel recoveries of 75-80% were common. Productivities of over 160t/manshift (face and maintenance) were regularly achieved but with the high manpower requirements and safety problems inherent with the room and pillar drill blast system, the method was not acceptable.

The first major changes saw the introduction of the Goodman continuous miners for excavation, and belt conveyors for main transportation. Productivites per manshift essentially remained the same, but manpower requirements declined whilst safety improved.

The ripperhead miners have now displaced the borer type continuous mines, since they are more flexible and can deal with varying seam heights and are also capable of cutting the harder sulphite ores which are often present.

Present day mining methods include - standard room and pillar with or without pillar mining, room and pillar (Chevron pattern) and a form of shortwall mining using yielding pillars for controlled lowering of the roof. (The mines using this method describe it as a modified longwall). This latter system, described in more detail later enables a higher percentage panel extraction to be obtained (90-92%) than from the Chevron room and pillar mining (75-80%), and still maintain good roof control.

Since mines are now having to work the lower grade seams, trends are towards the use of lower height mining equipment or selective mining to reduce the amount of waste salt in the mined product.

In general, ground stability in the Carlsbad basin is good although mining is occasionally complicated by the presence of gas (97%

N_2, 3% CH_4) in the clay bands above the potash beds. Salt back cover is massive, of the order of 200 m or more, however maximum opening widths have to be controlled to prevent failure of the roof beds due to the complicating presence of clay bands. Maximum room widths vary from 11 to 15 metres.

Where conventional room and pillar mining is practised (Figure 4-5), panels are developed on 7 to 11 entry blocks with roadway widths ranging from 9 m to 11 m and pillars ranging from 13.7 m, 15.2 m or 18.3 m square to rectangular at 6 m x 27.4 m to 9 m x 27.4 m. Mining is mainly carried out by ripperhead type continuous miners feeding into shuttle cars which travel up to 200 m to discharge through feeder breakers onto belt conveyors for transport to the shaft bins. Of the three mines still operating room and pillar systems, only one is pillar mining on a regular basis achieving a 90% recovery in the panel and 70% overall; compared with approximately 52% and 40% for the mines which do not mine the pillars. The high percentage recovery in the room and pillar systems reflects the good conditions generally present in the Carlsbad field.

Where room and chevron pillar mining is operated, at depths averaging 500 m, recoveries in panel are between 50 and 55%. Typical layout (Figure 4-6) comprises a 350 m x 305 m panel, developed by driving 3-7.6 m wide entries with 15.2 m diamond pillars between. When the far extent of the panel is reached, two pass entries are driven on each side at 45.7 m centres, for 122 m. Single pass rooms (3.8 m wide) are driven off either side at 60° for approximately 26 m. A 0.9 m pillar is left between each 60° room. Rooms are formed on the retreat. A rib pillar 9 m wide is left after every one or two sets of angled rooms. Mining is generally by ripperhead miners, shuttlecars, feeder breakers and conveyors.

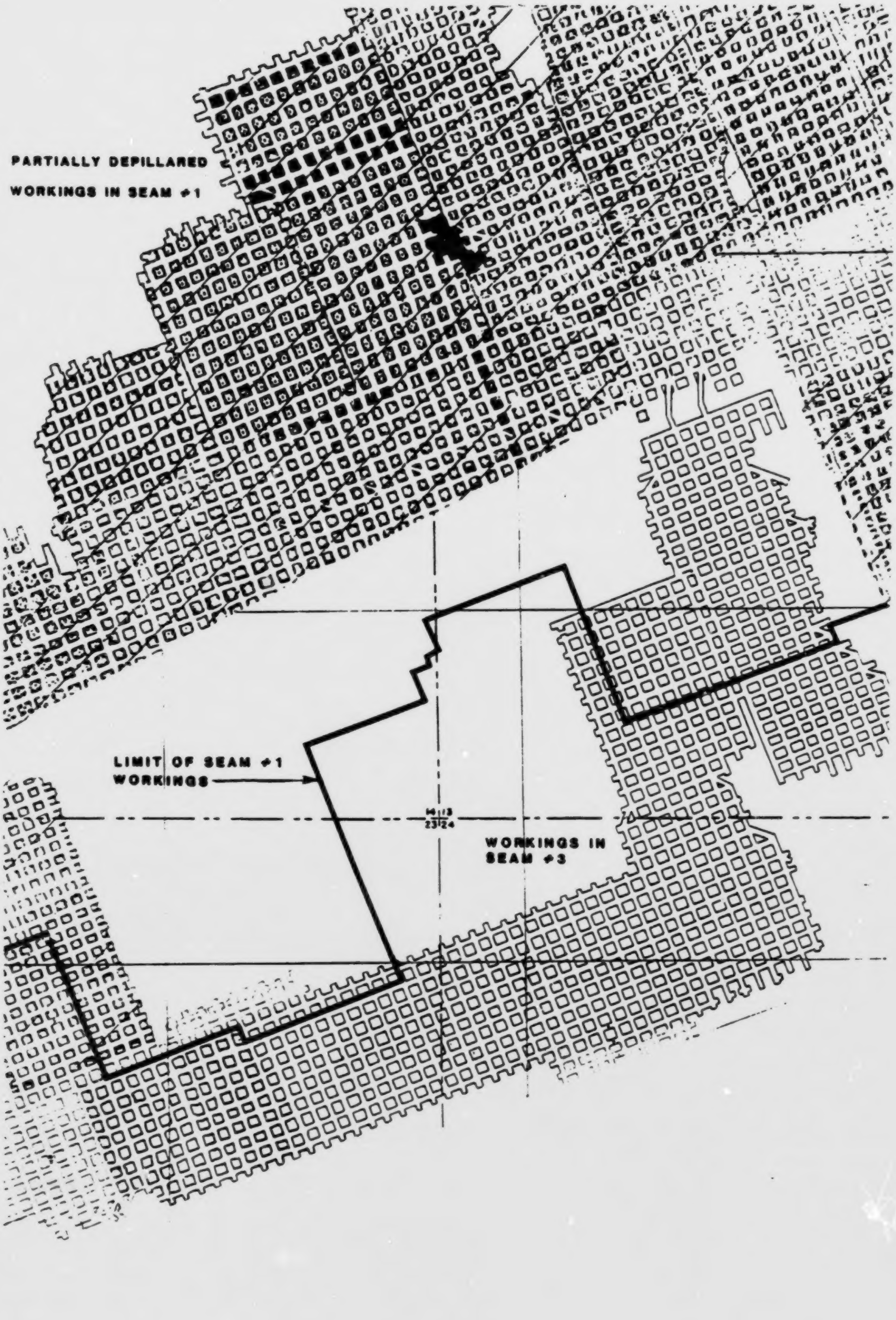

PARTIALLY DEPILLARED
WORKINGS IN SEAM #1
LIMIT OF SEAM #1
WORKINGS
14|13
23|24
WORKINGS IN
SEAM #3

FIGURE 4-5 CONVENTIONAL ROOM & PILLAR MINING IN TWO SEAMS

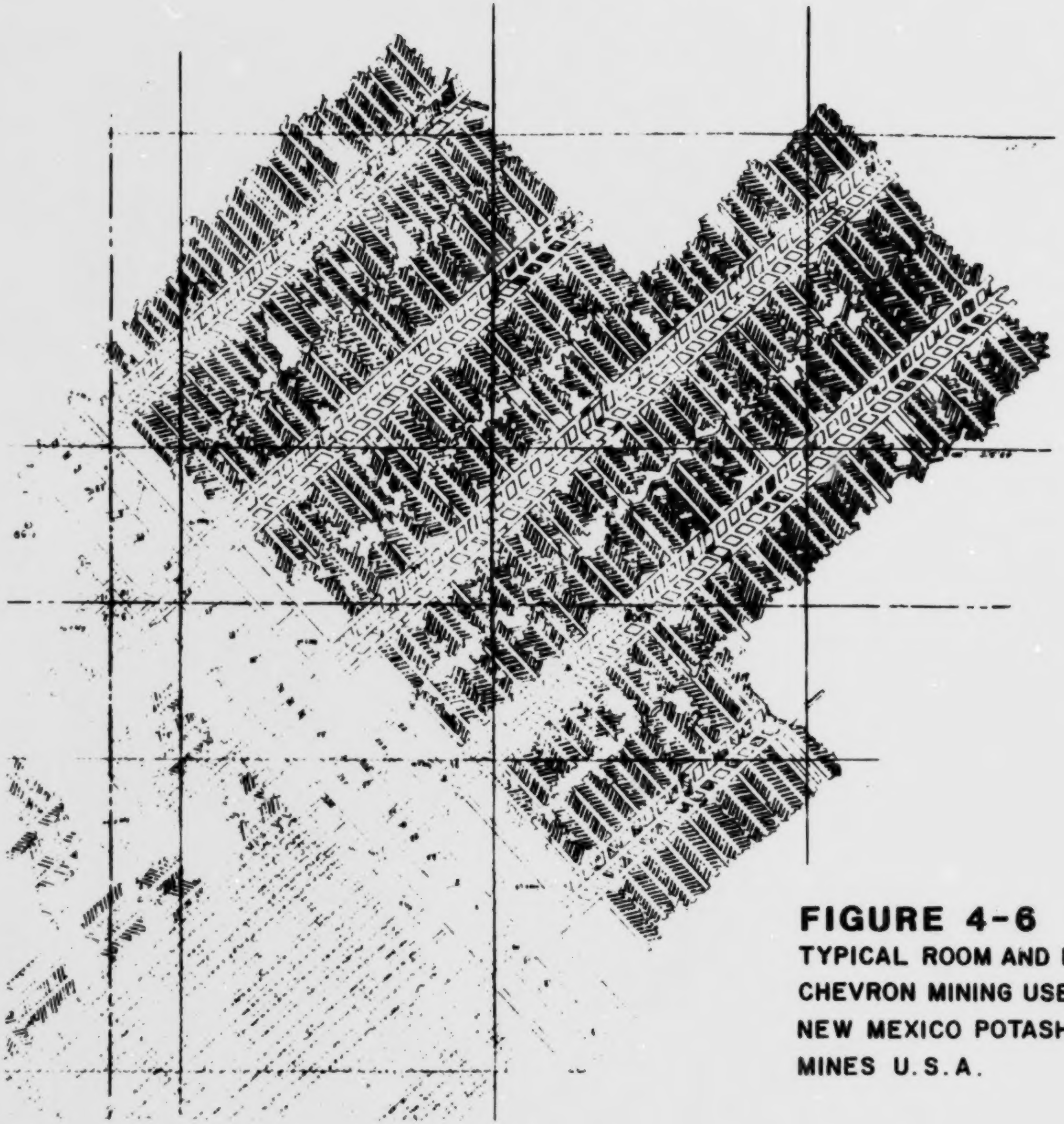


FIGURE 4-6
TYPICAL ROOM AND PILLAR CHEVRON MINING USED IN NEW MEXICO POTASH MINES U.S.A.

The most interesting and most recent change to mining methods in the Carlsbad basin in the use by two companies of the shortwall system of mining.

A panel up to 305 m wide and up to 762 m long is accessed by driving 3 or 4 9.1 m or 11 m entries along the centreline. Pillars are diamond shaped being either 6 m wide by 21.3 m long or 9.1 m wide by27.4 m long. Crosscuts are driven at 60° (Figure 4-7).

When the far limit of the panel is reached, mining commences on either side of the access entries. The ripperhead miner drives a 3 or 4 pass room (9 m or 15 m wide depending on the mine and the miner model) for 120-140 m, forming, on the retreat side a 2.4 m deep 3.1 or 3.8 m wide 60° crosscut, every 9 m. When the room is completed, a 1.8 or 2.4 m wide pillar is left and the next 9-15 m wide room commenced. The first pass of this room is alongside the pillar, and as it is mined, the 60° crosscuts are intersected, the pillar line thus becoming a series of small yielding pillars. These crosscuts assist with ventilation and dust control. As the panel is mined out on the retreat, the pillars of the central entries are also extracted. The ripperhead miners are served by shuttle cars delivering via feeder breakers onto the conveyor transportation system. Maximum one way hauls are 200 metres.

In one mine, waste salt above the potash beds has to be mined to provide working head room. This salt is mined separately and dumped by the shuttlecar in the previous mined out room, where it eventually assists with roof control (Figure 4-8).

The control of the roof in this 92% extraction mining system is excellent. The small pillars act as yielding pillars which severely deform and allow the roof to lower uniformly. Some areas can be seen which have been mined by this method three years previously, and convergence is only between 0.3 m and 0.4 m of the original mined height of

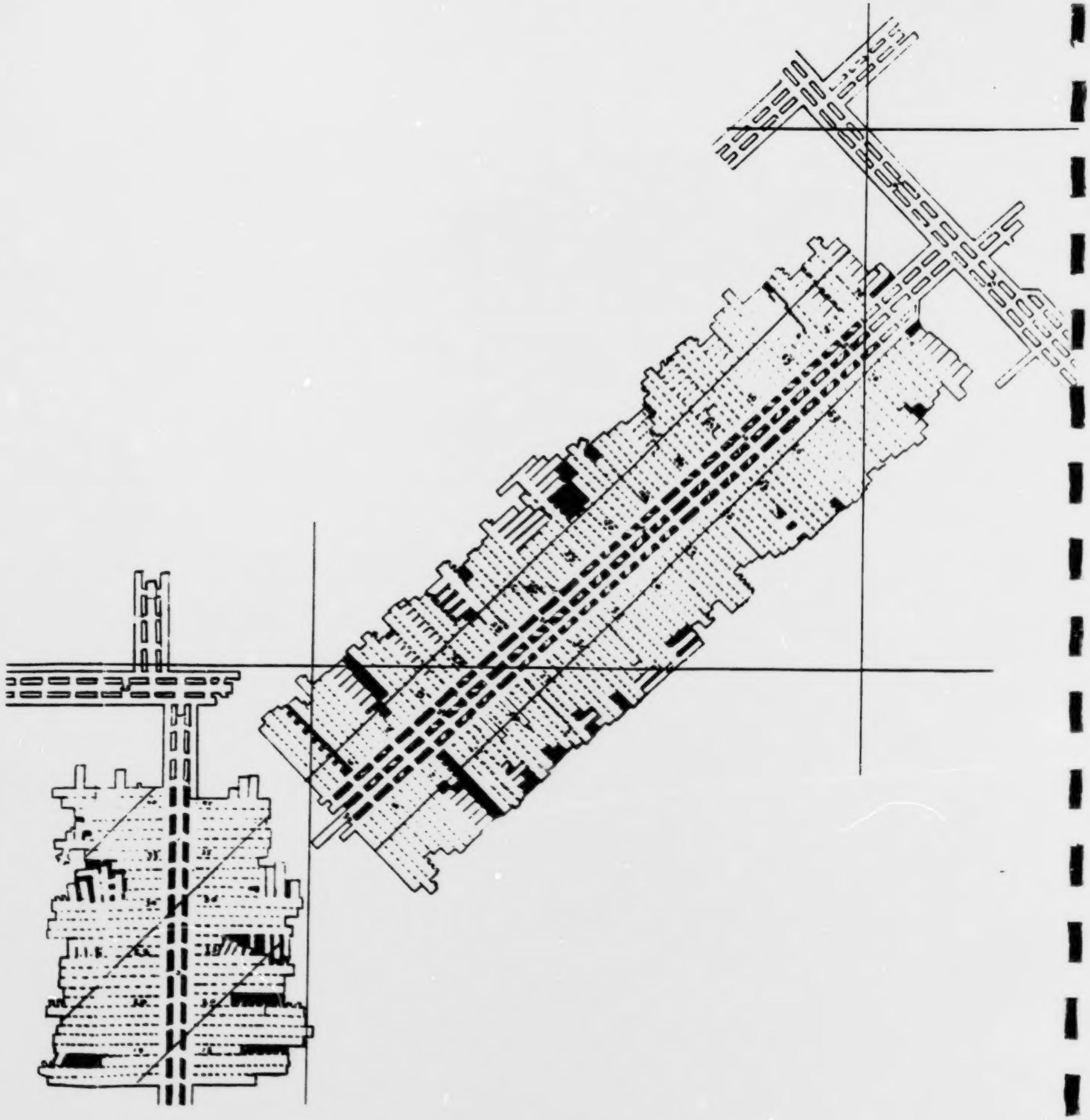


FIGURE 4-7 PLAN SHOWING TYPICAL SHORTWALL SYSTEM A WITH YIELDING PILLARS

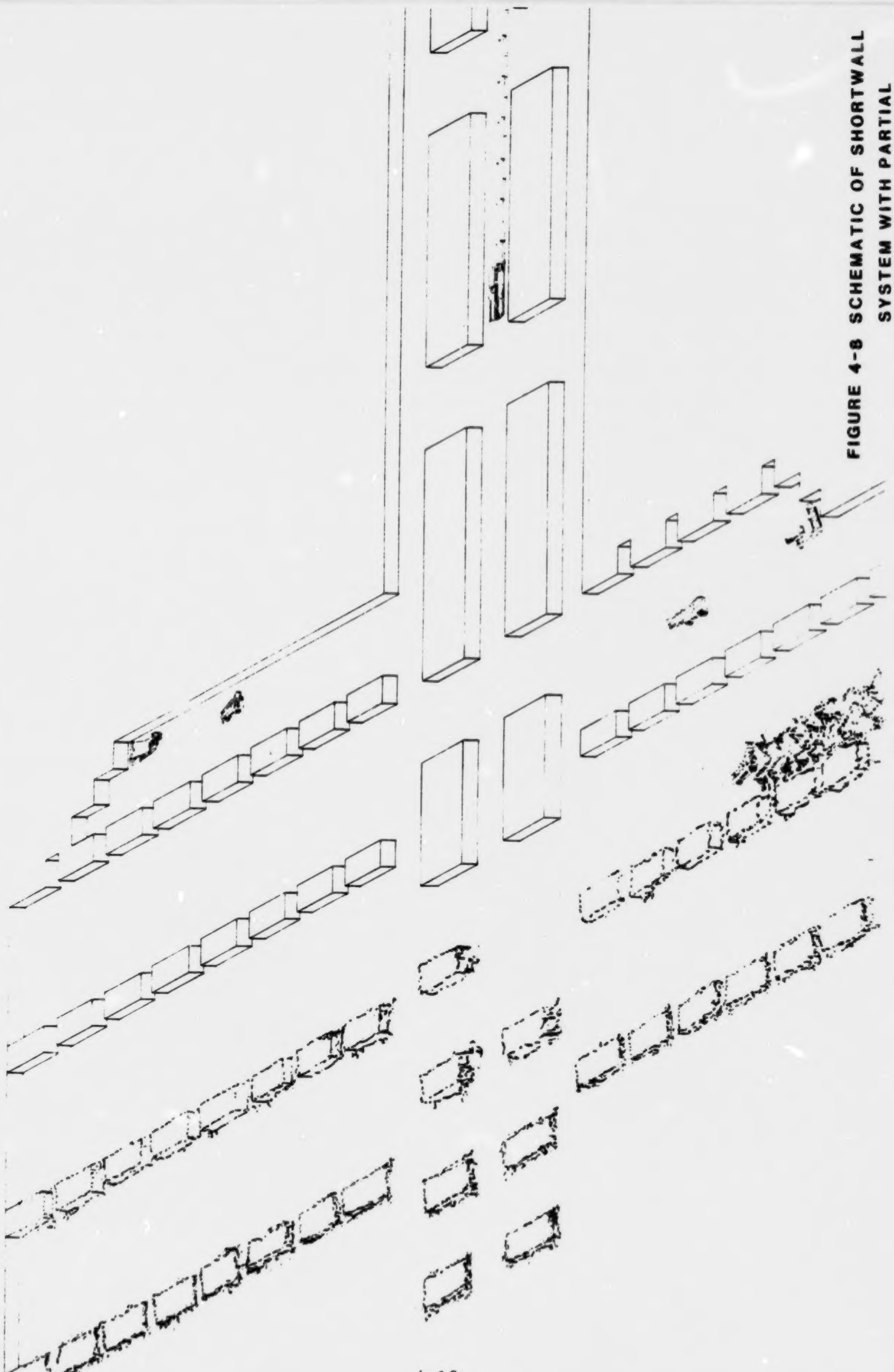


FIGURE 4-8 SCHEMATIC OF SHORTWALL SYSTEM WITH PARTIAL BACKFILL

1.4 m. However, experience has also shown that if the room width is increased by one further pass, considerable problems develop with roof stability and vastly increased rates of convergence occur as do minor roof falls. In normal circumstances, the convergence in these shortwall systems averages between 12 and 25 mm per day for the first 30 days and decreases thereafter. Surface subsidence over extended areas of shortwall working has reached 75% of the seam height extracted. No trouble has been experienced with the Rust aquifer which lies some 140 metres above the mining zone.

With modifications, we believe that this method of mining has application to both the Esterhazy and Saskatoon potash mining regions in Saskatchewan. This is dealt with in more detail in Part 6.

413 GEOTECHNICAL ASPECTS

Probably the most important geotechnical aspect of mining potash in the Carlsbad area of New Mexico is the high extraction ratio that has been achieved, up to 92% in the panels and 70% overall, and yet safe conditions have been maintained. The main factors that have permitted the high extractions are the modest depth of the workings below surface typically 300 m with a maximum depth of approximately 520 m and a thick evaporite sequence of approximately 140 m above the mining horizons providing an impermeable barrier between the workings and overlying aquifers.

Mining commenced in the area in the 1930's to 1950's generally using a conventional room and pillar mining method, with predominantly square pillars ranging between approximately 14 and 28 m in size and rooms ranging between approximately 5 and 11 m wide. One of the mines commenced mining with this conventional room and pillar layout but soon changed to retreat mining with rooms approximately 4 m wide at 60° to the sub-main entries and separated by pillars 3 m wide.

Pillar mining has been undertaken over the years in a number of the mines. This has been achieved with minimim ground control problems and in some cases pillars have been mined out to 2.4 m by 2.4 m in size.

In recent times, at least two mines have adopted a short wall mining method with width of extraction ranging from approximatley 9 m to 15 m separated by either strip pillars 2.3 m wide or rectangular pillars 4.3 m by 2.4 m separated by a 4 m gap. The primary role of the pillars is to support the working back which often contains a number of clay seams. The pillars are quite stable close to the working face but undergo severe crushing as the face advances. Even though the pillars crush, they still limit convergence and contribute to a reduction in surface subsidence compared with complete extraction. The pillars permit convergence to occur in a controlled manner and prevent potential air blasts developing from slabs falling from the back over a large areas.

Crushing of highly stressed pillars develops by fracturing and spalling at the edge of the pillar where the potash is under a high uniaxial stress state. The fracturing is often initiated at horizons where clay beds are evident.

For spans up to 9 m and in some cases up to 15 m, the roof is quite stable and only random bolting, or systematic bolting of intersections, is adopted. Both are generally mechanically anchored 1.0 m to 1.5 m long, although some resin grouted bolts have also been used. Thin clay seams are quite prominent in the roof and these have likely prevented the adoption of wider spans. No back fill has been used in the mines, except for the storage of waste products in some isolated cases. These waste products contribute marginally to the stability of the mine.

Gas is present in a number of the mines within the clay seams in the roof. If the pressure of this gas is not released, roof failures are more likely to develop and bleeding is often carried out on a regular basis by drilling up to the clay beds above.

Convergence in the mines is very dependent on the extracion. In heavily extracted areas (80 to 90% extraction), the long term creep rate typically varies from approximately 150 mm to 300 mm per year although local floor heave may suggest a higher rate in some areas. In low extraction areas (60% extraction) or roadways protected by pillars, the long term convergence rate is typically 25 mm to 50 mm per year or less. Approximately 75% of pillar convergence in the mine is reflected as subsidence on surface, although surface subsidence does not pose any problems in itself. None of the convergence or roof movements that have occurred have resulted in major break-up or collapse of the roof and instead the roof deforms gradually as it converges with the floor. In one of the mines in the area, a roadway was excavated approximately 3.5 m above a heavily extracted mining area and there is very little evidence of subsidence or associated fracturing in the roadway. This demonstrates the gradual and controlled nature in which convergence develops.

At one of the mines, deformation measurements have been taken in both excavations and pillars during the mining of potash by the shortwall system with yielding pillars. More than 90% of the ore is extracted leaving approximately 10% in the form of a symmetrical array of small pillars which undergo severe deformations over relatively short periods of time. The measurements monitored large deformations all the way to failure. The following measurements were taken:

- Pillar deformation
- Roof and floor closure between the pillars and rows of pillars
- Separation of strata due to mine deformation
- Stress measurements in pillars

These measurements were centred on one of the small yielding pillars in the centre of each panel. The pillars are approximately 2.4 m x 6.1 m, 3.1 m apart with 18.3 metres between rows. The nearest boundary was between 45 and 60 metres away. A second pillar, 24.4 m long, was used in a second similar situation (Fig. 4-9).

Typical results were:

A. Small Pillar (2.4 m x 6.1 m)

1.	Roof-floor closure	- 25 mm/day for first 30 days - slower thereafter - 2/3 from roof convergence, 1/3 from floor heave - closure uniform in room - closure at centre of room similar to that between pillars - face advance 20 metres per week
2.	Pillar Extension	- on width elongations of 12 to 17 mm per day for 30 days - on length elongations of 17 mm per day for 30 days - no change in the centre core (1/4) of the pillar
3.	Floor & Roof Strata	- no appreciable separation of roof or floor strata within 10 metres

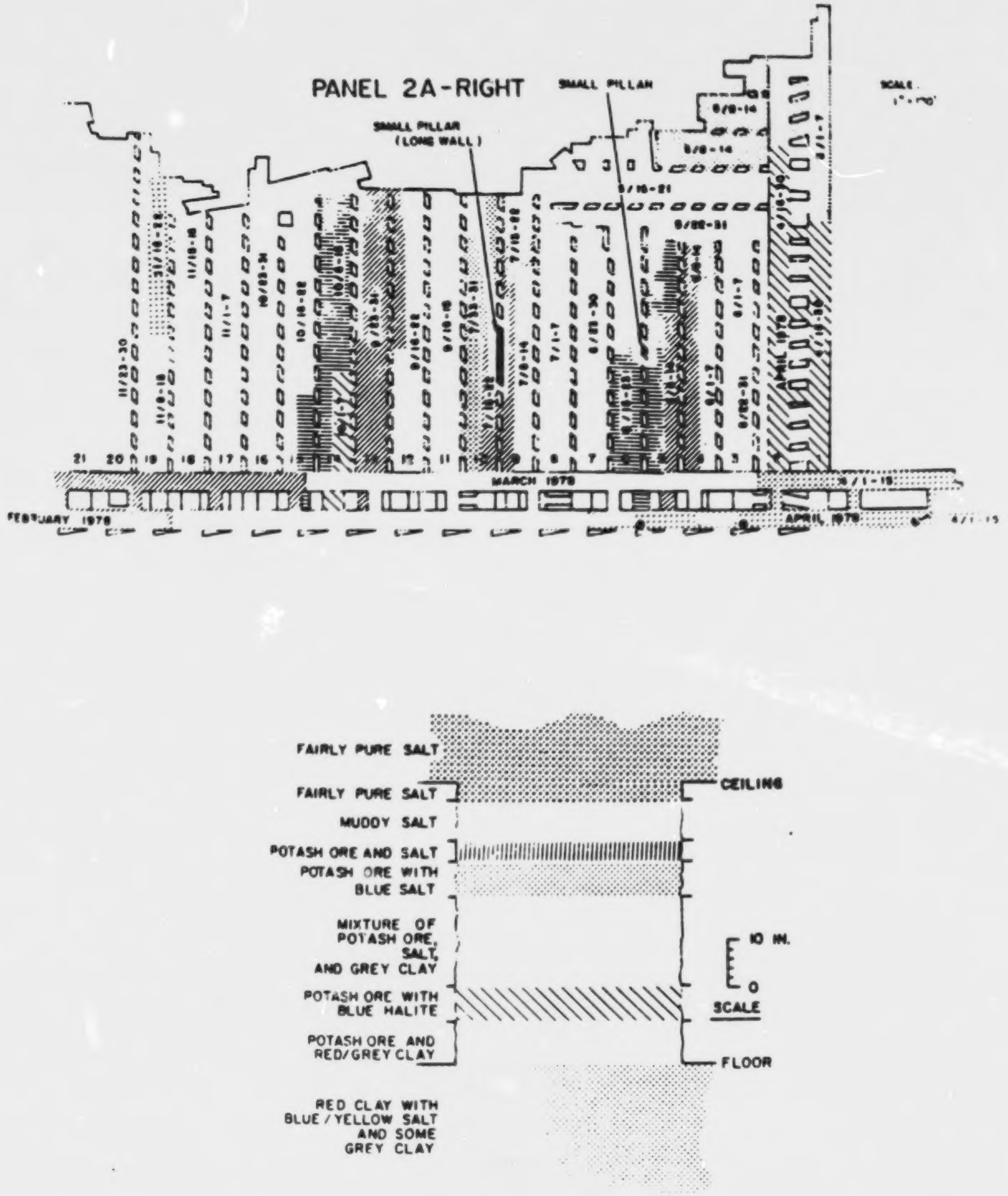

PANEL 2A-RIGHT
SMALL PILLAR
SMALL PILLAR (LONG WALL)
SCALE
MARCH 1979
FEBRUARY 1979
APRIL 1979
21
20
19
18
17
16
12
11
8
7
3
FAIRLY PURE SALT
FAIRLY PURE SALT
CEILING
MUDDY SALT
POTASH ORE AND SALT
POTASH ORE WITH BLUE SALT
MIXTURE OF POTASH ORE, SALT, AND GREY CLAY
10 IN.
0
SCALE
POTASH ORE WITH BLUE HALITE
POTASH ORE AND RED/GREY CLAY
FLOOR
RED CLAY WITH BLUE / YELLOW SALT AND SOME GREY CLAY

FIGURE 4-9 LOCATION OF PILLARS IN SHORTWALL MINING FOR CONVERGENCE TESTS

4. General data - after 30 days
floor lift = 200 mm
roof lowering = 560 mm
- pillar slabbing occurred on a continuous basis

B. Large Pillar (2.4 m x 18.3 m)

1. Roof-floor closure - 8 mm/day for 30 days
2. Pillar Extension - 6 mm/day for 30 days

The longer pillar thus offers stiffer control to the lowering of the roof, but of course lowers the extraction ratio.

The mines in the Carlsbad area have been operating for a number of years and have developed over this time mining methods to achieve a high extraction ratio under safe and stable mining conditions.

A number of geological features have been identified in the mines such as dykes, folds, breccia pipes, and oil and water seeps. However none of these have caused any significant stability problems.

4.2 U.S.A. - UTAH - PARADOX BASIN

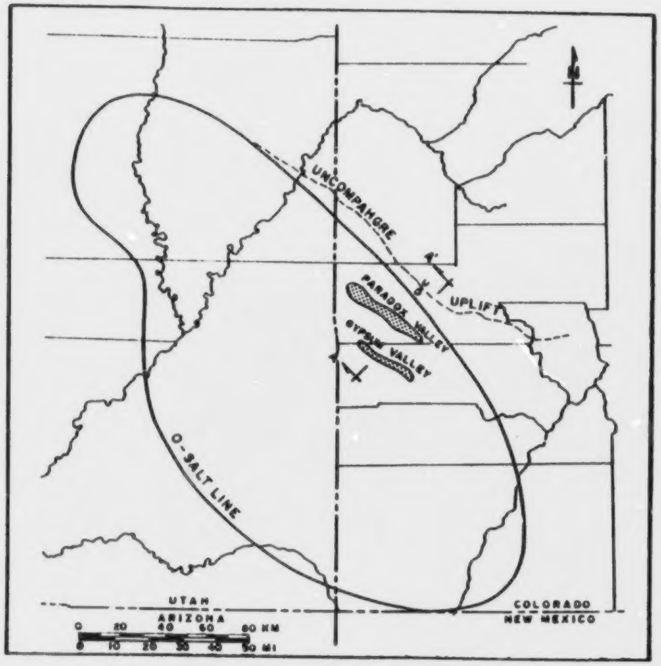
421 GEOLOGICAL ASPECTS

The Paradox Basin of southeastern Utah and Southwestern Colorado includes extensive salt deposits within the Middle Pennsylvanian Paradox Member of the Hermosa Formation (Figure 4-10). Intense deformation and flow has altered the original thickness of these deposits from approximately 1500 metres to as much as 4000 metres. The basin is surrounded by structural highs generated in Mississippian to Pennsylvannian times. Development of a series of northwest-southeast orientated fold axes is the result of deformation maximized during the Laramide Orogeny.

There is a general facies change from arkosic deposits in the east, evaporites centrally, and carbonates to the west. Distinct depositional cycles are noted within the evaporitic strate with a normal upwards progression from basal carbonates, and anhydrite, to halite (with or without potash), overlain by more anhydrite, and finally capped by additional carbonate. Individual cycles may vary from 1 to 30 metres in thickness and a total of 29 cycles are present in the basin. Eighteen of these cycles contain potash beds, 11 of which may constitute economically viable ore zones. The numbers 5 and 9 cycles are of greatest economic value (Figure 4-11).

The potash zones show widespread lateral continuity and most commonly contain sylvite and carnallite. The K_2O contents may exceed 30 percent.

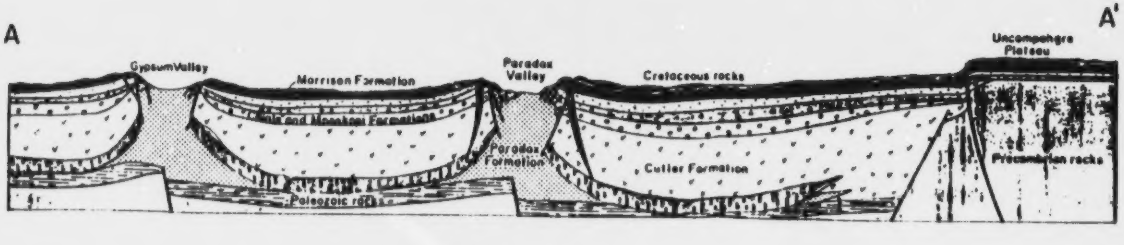
The Texasgulf mine in the Cane Creek Anticline area intersects potash at about 1200 metres in depth. The ore zone is 3.4 metres thick and contains 25 to 30 percent K_2O in the form of sylvinite. The strata


UNCOMPAHGRE
UPLIFT
A'
PARADOX VALLEY
GYPSUM VALLEY
A
O-SALT LINE
UTAH
ARIZONA
COLORADO
NEW MEXICO
0 20 40 60 80 KM
0 10 20 30 40 50 MI

LOCATION MAP

EXPLANATION

■	Cretaceous rocks
■	Morrison Formation
▨	San Rafael Group
■	Glen Canyon Group
▨	Moenkopi Formation
☐	Cutler Formation
▨	Honaker Trail Formation
▨	Paradox Formation
▤	Pinkerton Formation and Pre-Pennsylvanian Paleozoic rocks
☐	Precambrian rocks


A
A'
Gypsum Valley
Morrison Formation
Chinle and Moenkopi Formations
Paradox Valley
Paradox Formation
Cretaceous rocks
Cutler Formation
Uncompahgre Plateau
Precambrian rocks
Paleozoic rocks

SECTION A - A'
NOT TO SCALE

FIGURE 4-10 REGIONAL GEOLOGY AND CROSS SECTION OF PARADOX REGION

ERA	SYSTEM	SERIES	FORMATION	THICKNESS (ft)	LITHOLOGY	TIME (BP) (my)
CENOZOIC	QUATERNARY AND TERTIARY		Quaternary deposits Tertiary intrusives Wasatch Formation	0-?	Quaternary and Tertiary fluvial and eolian deposits: Tertiary volcanics and intrusive rocks: Red beds and conglomerates	70
MESOZOIC	CRETACEOUS	UPPER	Mesaverde Group	0-500	Sandstone, siltstone, shale	
			Mancos Shale Ferron Member	1000-3500	Shale and siltstone Carboniferous shale	
			Dakota Sandstone	100-150	Conglomerate, sandstone and shale	
		LOWER	Burro Canyon Formation	100-200	Conglomerate, sandstone and shale	135
	JURASSIC		Morrison Formation Brushy Basin Member Salt Wash Member	300-400	Variegated claystone, siltstone and sandstone Siltstone Siltstone	
			Summerville Formation	25-100	Red shale and siltstone	
			Entrada Sandstone (San Rafael Group)	100-500	Dune sandstone	
			Carmel Formation (San Rafael Group)	75-100	Red shale and siltstone	
			Navajo Sandstone (Glen Canyon Group)	100-400	Dune sandstone	180
	— ? — ? — ? —	— ? — ? —	Kayenta Formation (Glen Canyon Group)	0-300	Red shale and sandstone	
	TRIASSIC		Wingate Sandstone (Glen Canyon Group)	0-450	Dune sandstone	
			Dolores Formation Chinle Member Moss Back Member Moenkopi Member	(?)-2000	Red siltstone Sandstone Red shale and siltstone } Dolores Fm. of Rico (1972)	225
PALEOZOIC	PERMIAN		White Rim De Chelly Organ Rock Cedar Mesa Halgaito Cutler Formation	1500-2000	Sandstone Dune sandstone Red shale and sandstone Sandstone Red shale and siltstone Grading into Arkose and conglomerate (Rico)	
			Rico	300-500		270
	PENNSYLVANIAN	VIRGIL-MISSOURI	Honaker Trail Fm. (Hermosa Group)	1000-2000	Dolomite and black shale	
		DES MOINES	Paradox Formation (Hermosa Group)	0-6000	Carbonates Saline deposits Grading into Arkose and conglomerate	
		ATOKA-MORROW	Pinkerton Trail Fm. (Hermosa Group)	0-200	Dolomite and black shale	
			Molas Formation	0-150	Red shale, siltstone, rubble (regolith)	305
	MISSISSIPPIAN		Leadville Limestone	200-500	Limestone and dolomite	350
	DEVONIAN		Ouray Limestone	75-100	Limestone	
			Elbert Dolomite McCracken Ss. Member	200-350	Dolomite and limestone with marine sandstone at base	
			Aneth Dolomite	0-200	Dolomite and minor sandstone and shale	400
	CAMBRIAN		Lynch Dolomite	0-400	Brown dolomite	
			Maxfield Limestone	(?)-660	Limestone and shale	
			Ophir Shale	0-500	Shale	
			Ignacio Quartzite	0-200	Quartzitic sandstone and conglomerate	600
PRECAMBRIAN			Unnamed	18,000(?)	Sediments and metasediments Schists, gneisses, quartzites, intrusives	

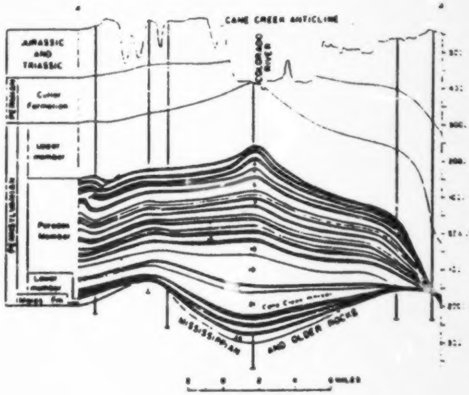


FIGURE 4-11
GENERALIZED GEOLOGIC COLUMN
OF THE PARADOX BEDDED SALT REGION
SHOWING POTASH ZONES

have been determined to be highly faulted and folded. Initial mining by conventional methods was discontinued due to structural complexities, excessive rock pressures, and high formational temperatures. Solution mining approaches have since proven to be more successful.

422 MINING METHODS

There is only one mining operation in the Paradox basin in Utah. The Cane Creek mine of Texasgulf is unusual in that it was initially designed and operated as a conventional room and pillar mine, but was later converted to the present solution mining operation.

Production first started at the mine in 1964 at a depth of 915 metres. Initial surface exploration had suggested a deposit dipping uniformly at 15%, but very steep local folding (0-25 degrees) was encountered, which is evidenced in the irregular mining pattern seen in the N.E. portion of the mine map (Figure 4-12). The mine was also very gassy and the scene of an explosion during early development. The rolling undulations complicated normal continuous mining operations. Rock pressures were high and a further complication was that roof conditions were bad, necessitating the leaving of a layer of potash in the roof, and thus a loss in ore extraction.

Rooms 5.5 m wide and 2.4 or 3.1 m high depending on the miner type were driven, and although many variations were tried, including conventional room and pillar with and without pillar mining; long rooms; short rooms; varying pillar sizes; the ground control problems could not be eliminated (Figure 4-12). Extraction percentages ranged from a general average of 20% to 80% in areas where pillar mining was attempted. At one time, the main and sub-main headings were driven in the salt member below the sylvite zones. These roadways were better, but those in the potash member were very poor where it was

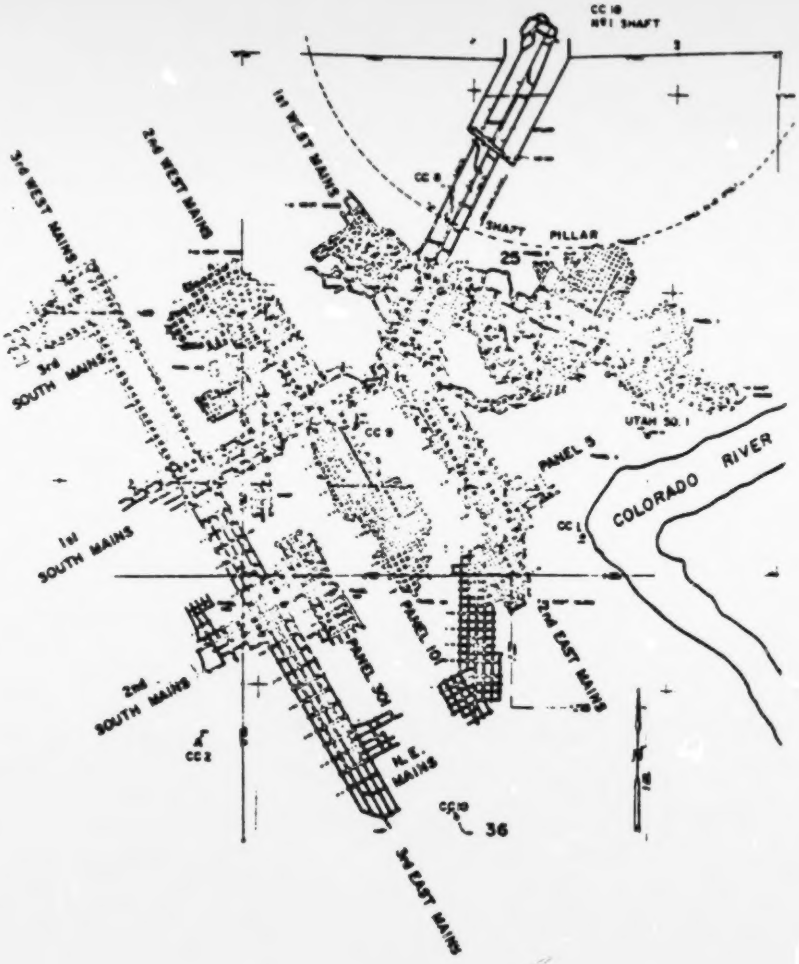

CC 10
Nº1 SHAFT
1st WEST MAINS
2nd WEST MAINS
3rd WEST MAINS
CC 8
SHAFT PILLAR
25
3rd
SOUTH MAINS
CC 9
UTAH SO. 1
PANEL 5
COLORADO RIVER
CC 1
1st
SOUTH MAINS
PANEL 101
2nd EAST MAINS
PANEL 301
2nd
SOUTH MAINS
CC 2
N.E.
MAINS
CC 10
36
3rd EAST MAINS

FIGURE 4-12
1967 UNDERGROUND WORKINGS
CANE CREEK POTASH MINE
PRIOR TO ABANDONMENT 1970

necessary to leave at least 1.5 m of the potash member between the excavation and the overlying shale and anhydrite sections of the clastic member 4. This severely affected the mine's production and productivity since the highest potash grades were being left in the roof. At the time the mine was designed, the thickness of potash calculated by the mine design consultant as being necessary for stability was 0.3 metres.

These problems resulted in the mine never achieving its rated capacity and never making an overall profit. Following extensive investigation, a decision was made in 1970 to convert the mine to a solution mining operation with advantage being taken of the local climate (200 mm rain per year) to establish solar ponds to crystallize out the potash salts.

Whilst all underground equipment was removed and the mine sealed, a series of 12 wells was drilled from the surface into the existing mine workings. Some of these entered the mines at the anticline axes and other at the syncline axis (Figure 4-13). The mine was flooded with 2.8 billion litres of fresh water. Water is now injected into the mine at the same time brine is being withdrawn to maintain a flooded brine/water balance within the potash horizon. Approximately 45% more water is injected than is withdrawn as brine, since the voids of the salts which go into solution have to be filled.

It takes up to 300 days retention in the mine to produce the brine. Water is injected into the higher parts of the seam and brine, being heavier, is withdrawn from the lower parts of the mine. By the time the brine is withdrawn from the mine, it has reached rock equilibrium temperature of about 32°C (92°F).

There were approximately 540 kms (340 miles) of roadways in the mine at the time of closure. The pillars and walls are estimated to

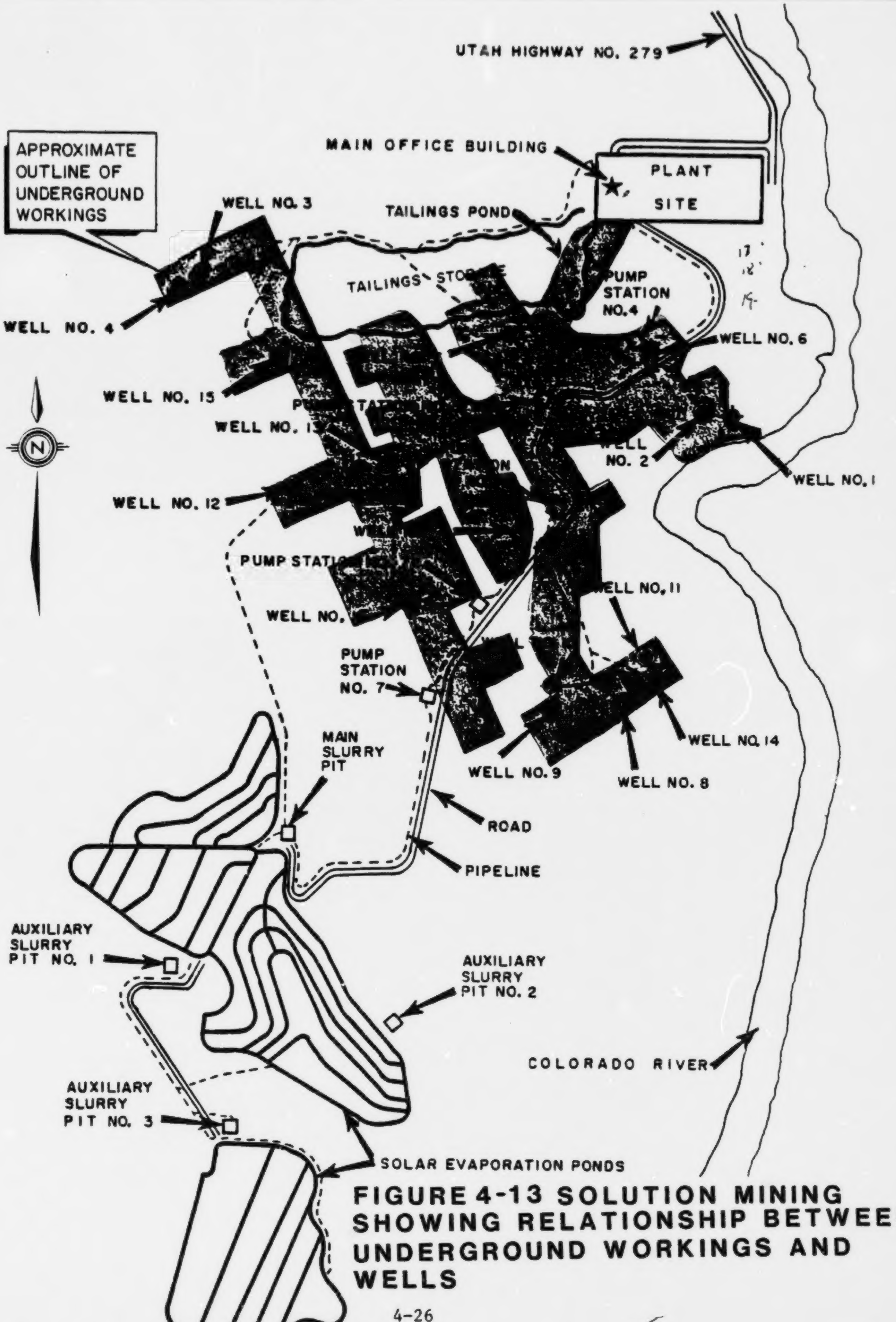

UTAH HIGHWAY NO. 279
APPROXIMATE OUTLINE OF UNDERGROUND WORKINGS
MAIN OFFICE BUILDING
PLANT SITE
WELL NO. 3
TAILINGS POND
TAILINGS STOR
PUMP STATION NO. 4
WELL NO. 4
WELL NO. 6
WELL NO. 15
PU STAT 1
WELL NO. 13
ON
WELL NO. 2
WELL NO. 1
WELL NO. 12
WE
PUMP STATI
WELL NO. 11
WELL NO.
WELL
PUMP STATION NO. 7
MAIN SLURRY PIT
WELL NO. 14
WELL NO. 9
WELL NO. 8
ROAD
PIPELINE
AUXILIARY SLURRY PIT NO. 1
AUXILIARY SLURRY PIT NO. 2
COLORADO RIVER
AUXILIARY SLURRY PIT NO. 3
SOLAR EVAPORATION PONDS
N

FIGURE 4-13 SOLUTION MINING SHOWING RELATIONSHIP BETWEEN UNDERGROUND WORKINGS AND WELLS

be gradually dissolving at rates of between 150 mm and 300 mm year year.

The potash bearing brine is pumped to a series of solar ponds which cover 160 ha (400 acres) some 5 kms from the mine site. Individual ponds, which are lined with a 20 mm thick PVC material, vary from 2.5 ha (6 acres) to 21 ha (52 acres) in size. During emplacement, a blue dye is injected into the brine to ensure that the maximum amount of solar heat is retained to enhance the crystallization of the potash in the ponds. In the six summer months, brine is pumped into the ponds and the sun's heat used to evaporate moisture and crystallize the potash salts. In the three winter months, the brine from the mine is pumped to the ponds, where a cold recrystallization takes place due to the very rapid drop in temperature.

Once crystallization has been completed in any pond, the remaining liquor is decanted into the pond below, and the deposited salts drained. They are then mined by elevating scrapers, taken to slurry mixing tanks, where they are put into saturated brine at 30% solids ratio and pumped back to the process plant at the mine site for potash recovery through standard flotation and compaction processes.

The mine currently has some 16 wells into the old workings, and has drilled additional wells close to but outside the limit of the old mine workings and attempted to fracture the potash bed and contact the old workings and thus extend the solution mined area. This has not been successful due, it is believed, to the fact that the potash beds adjacent to the workings are subject to the abutment pressures arising from the conventional extraction and are thus not amenable to hydrofracturing.

The solution mining has been undertaken for approximately 12 years and is expected to need about the same period again to recover the remaining potash within the old mine workings at a rate of 300,000 tons K_2O per year.

We believe that the successful change from conventional underground mining to solution mining made at Cane Creek, has longterm applications to the Saskatchewan potash industry and possibly also to the New Brunswick potash industry. This is discussed further in Part 6.

423 GEOTECHNICAL ASPECTS

The most significant characteristic of the Cane Creek deposit is the complexity of the geology and the extensive faulting and folding that it exhibits. Mining was attempted at a depth of 750 m below surface but it was found to be extremely difficult to control roof stability and floor heave. The stresses generated at the great depth below surface of 750 m and the impact of the complex geology meant that economic mining could not be achieved.

There appears to have been no underground geotechnical problems associated with the solution mining that has been operated since closing the underground workings.

4.3 U.S.A. GREEN RIVER BASIN - WYOMING - TRONA MINING

431 GEOLOGICAL AND MINING ASPECTS

A visit was made to one of four trona mines operating in the Green River Basin on Wyoming (Figure 4-14). Trona is of a similar nature to potash in terms of its structure and cuttability, and the particular mine visited was mining the trona by longwall caving and various room and pillar systems.

The Green River Basin is very extensive containing some 3700 million recoverable tons of trona. There are over 42 trona bearing zones in the sequence. The lowest seam (#1) is 20 ft. thick and at a depth of 3200 ft. Mining by solution mining is expected to start during this decade. The seams currently being mined are 17, 19, 20, 24 and 25. The mine is working the #17 seam which averages 10 ft. in thickness, and is almost flat lying (2%) across the take, apart from occasional minor rolls. The mine has been in operation for over 30 years having produced more than 63 Mt in that time from an area presently about 7 kms by 6.5 kms. Reserves are sufficient for a further 80 years at present rates (Figure 4-15).

The mine is working conventional room and pillar systems with square and rectangular pillars using either drill/blast equipment, rotor borer miners, or ripperhead type continuous miners, and for the past two years has been operating a longwall face. Present production comes 30% from drill/blast room and pillar, 50% from continuous miners and borers, and 20% from longwall.

Conventional mining is worked on a 9 or 10 entry system with the centre 3 entries being intake air and used for the conveyor belt, power and for travel. Recoveries in the room and pillar sections range

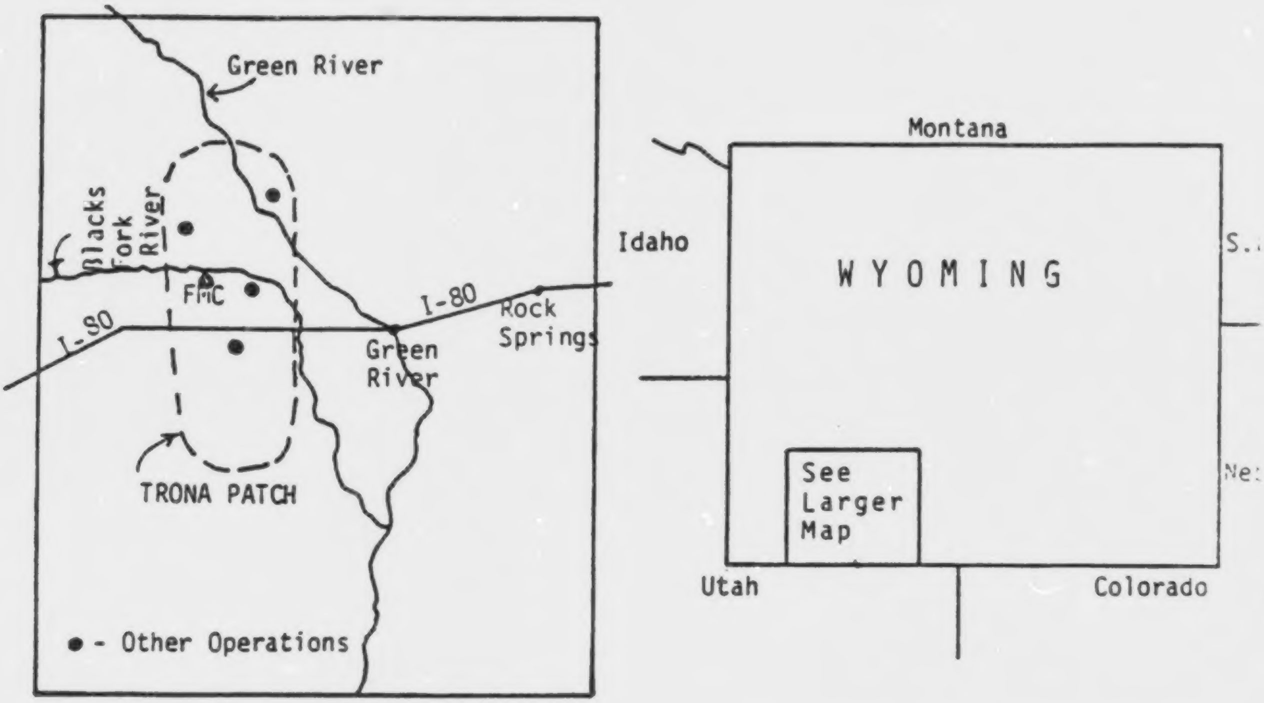

Green River
Blacks Fork River
FMC
I-80
I-80
Rock Springs
Green River
TRONA PATCH
• - Other Operations
Montana
Idaho
WYOMING
S.
Ne
See Larger Map
Utah
Colorado

FIGURE 4-14 LOCATION OF TRONA MINES WYOMING

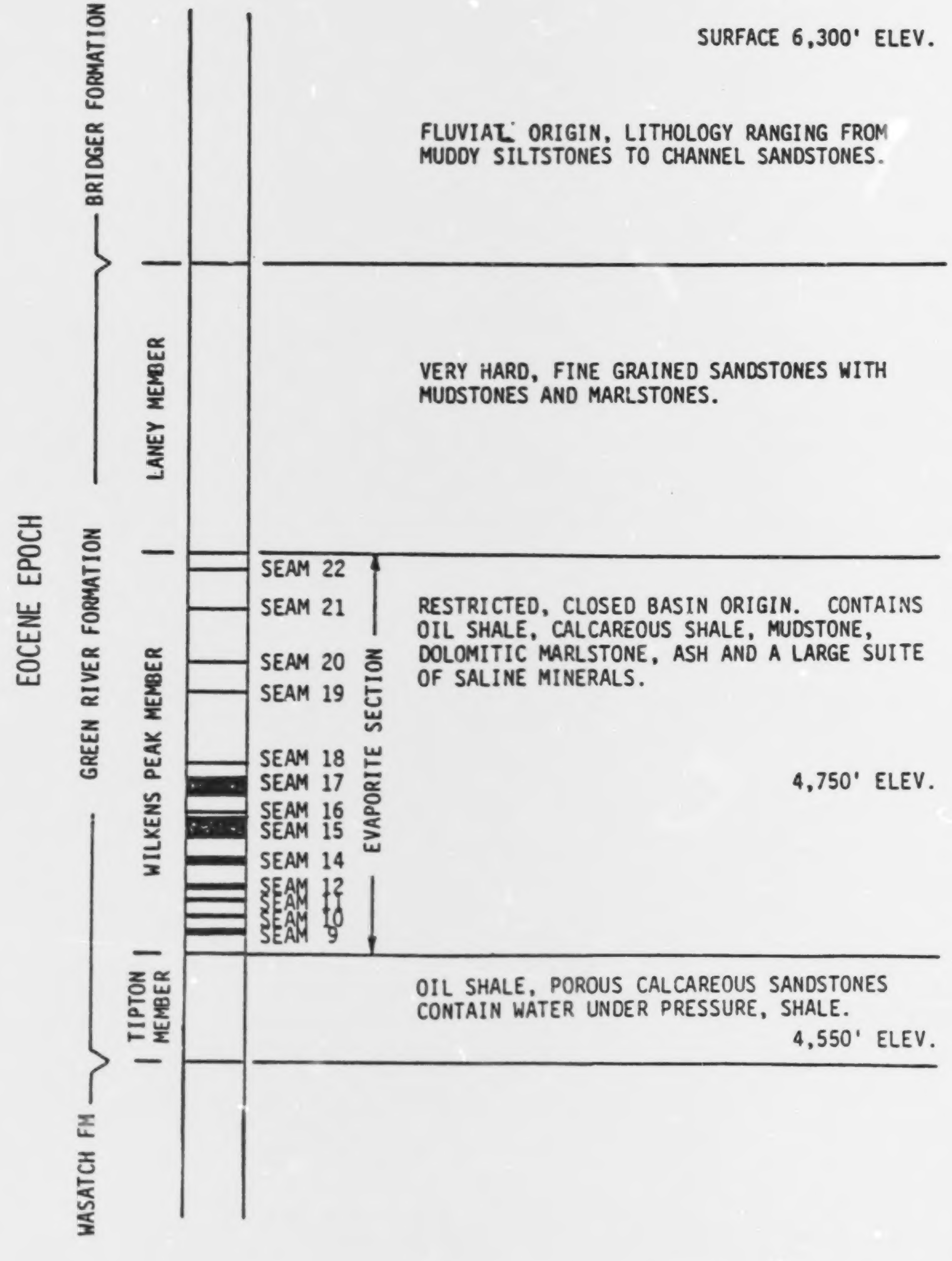

SURFACE 6,300' ELEV.
FLUVIAL ORIGIN, LITHOLOGY RANGING FROM MUDDY SILTSTONES TO CHANNEL SANDSTONES.
VERY HARD, FINE GRAINED SANDSTONES WITH MUDSTONES AND MARLSTONES.
RESTRICTED, CLOSED BASIN ORIGIN. CONTAINS OIL SHALE, CALCAREOUS SHALE, MUDSTONE, DOLOMITIC MARLSTONE, ASH AND A LARGE SUITE OF SALINE MINERALS.
4,750' ELEV.
OIL SHALE, POROUS CALCAREOUS SANDSTONES CONTAIN WATER UNDER PRESSURE, SHALE.
4,550' ELEV.
EOCENE EPOCH
BRIDGER FORMATION
GREEN RIVER FORMATION
WASATCH FM
LANEY MEMBER
WILKENS PEAK MEMBER
TIPTON MEMBER
EVAPORITE SECTION
SEAM 22
SEAM 21
SEAM 20
SEAM 19
SEAM 18
SEAM 17
SEAM 16
SEAM 15
SEAM 14
SEAM 12
SEAM 11
SEAM 10
SEAM 9

FIGURE 4-15 TYPICAL GEOLOGICAL SECTION - GREEN RIVER BASIN - WYOMING

up to 43% and are governed by roof conditions. In room and pillar operations the mine has found it necessary to leave a minimum of 0.5 m of trona in the roof to provide stable conditions and prevent the shales and thin trona bands above the main trona bed from collapsing into the mine roadways. The mine is a gassy mine having to use schedule 31 flame proof electrical equipment, the gas being present in the shales in the roof and holes are drilled on a regular basis into the roof to bleed off the gas. Mining operations normally take place on top of the 0.5 m oil shale band which forms the floor and which proves to be a competent surface on which all equipment can efficiently operate. In the drill/blast headings, an arc shearer is used to cut a vertical slot 3.4 m deep. Fourteen holes (three rows of two either side of the slot plus two extra lifters in the bottom) are drilled by hydraulic drills. Anfo explosives with water stemming and electric detonators are used. The round averages a 3.1 m pull giving approximately 70 tonnes of trona (using 50 kg Anfo).

The conventional drill blast panel is worked by a nine man crew using one arc shearer, one gathering arm loader, one drill rig, two shuttle cars, two bolting units and one powder unit.

A nine entry system is worked and normally 10 places are drilled, fired and loaded out in a shift resulting in production of 730 tonnes per shift. Conditions in the drill and blast headings are stable. There is very little sign of sloughing of pillars despite the obvious damage from blasting but they find it necessary to maintain at least 0.5 m of trona in the roof and in certain areas, particularly when approaching older workings, this is increased to approximately 0.7 m.

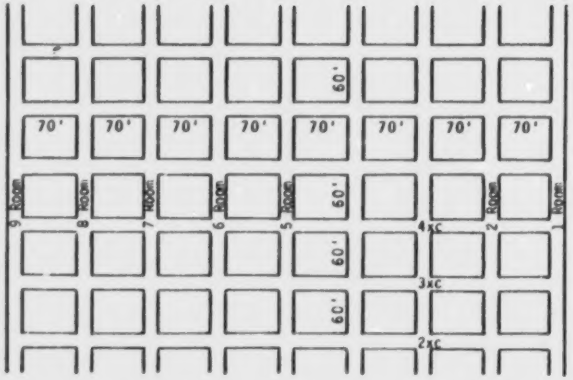
Rotor borers and ripperhead miners are used for both development drivage and room and pillar panel mining with rectangular and rather than square pillars. Miners are served by two shuttle cars and one bolting unit. There are two ripperhead miners per panel with a total panel crew of nine, whereas only one borer is used in a panel with a panel crew of five. The variation of pillar sizes (and recoveries) can be seen in Fig 4-16.

In one area of the old mine where attempts were made to mine the pillar and a 90% extraction was achieved over a small area, surface subsidence was 2.1 m out of an extracted height of 2.6 m. However, roof conditions deteriorated so badly in this section that it had to be abandoned and pillar mining has not been attempted since.

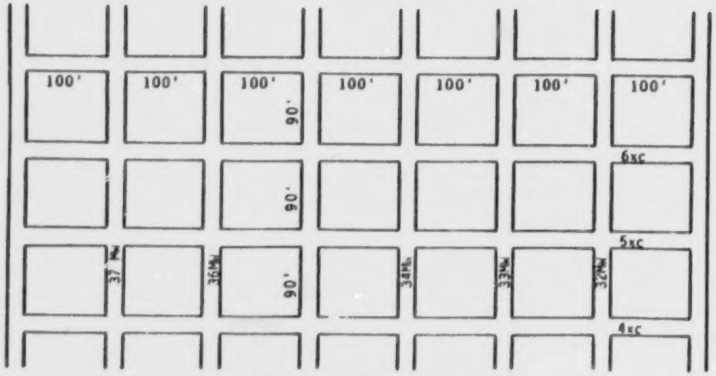
The longwall was introduced in March 1981 to try to improve recovery and safety. Longwall techniques are capable of extracting the full 3.1 m of height since the use of powered shield supports provides effective safe support along the full length of the face, thus raising panel recovery to over 80% including the between panel pillar.

The mine is generally blocked out on a north/south main drivage direction with panel lengths being approximately 1100 m. For the longwall trial, three panels were set aside for excavation by this system and once these three panels have been mined a decision will be made as to whether the mine will be converted to complete longwall operation as the older equipment comes up for renewal. The cost of setting up the longwall system which comprised the Anderson Strathclyde Astro 1000 shearer, a Dowty Meco heavy duty conveyor complete with crusher at the head end, Dowty stage loader, Dowty 550 ton four-leg shields, was of the order of nine million dollars.

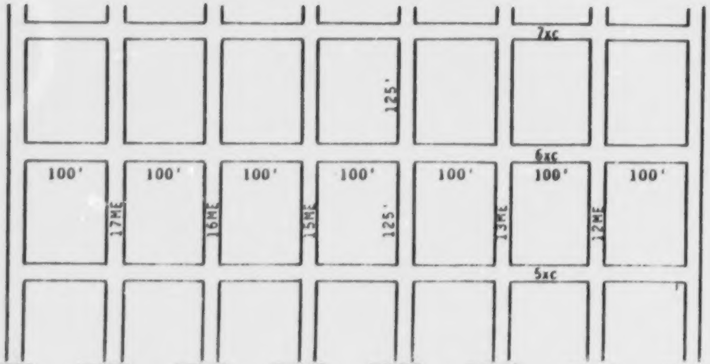
The section of the longwall face comprises, 0.3-0.45 m of oil shale forming the floor, 1.2 m of trona, a shale band, 0.3 m of trona, a shale band, 0.3 m of trona, a shale band, 0.9 m of trona and in the top 0.5 m numerous shale bands alternating with trona. Most of the shale bands do not exceed 25 mm in thickness. The machine extracts the full


70'
60'
1 Room
2 Room
5 Room
6 Room
7 Room
8 Room
9 Room
2xc
3xc
4xc

TYPICAL CONVENTIONAL PANEL


100'
90'
37 MH
36MH
34MH
33MH
32MH
4xc
5xc
6xc

TYPICAL DRUM MINER PANEL


100'
125'
17ME
16ME
15ME
13ME
12ME
5xc
6xc
7xc

TYPICAL BORER MINER PANEL

TYPICAL LONGWALL PANEL

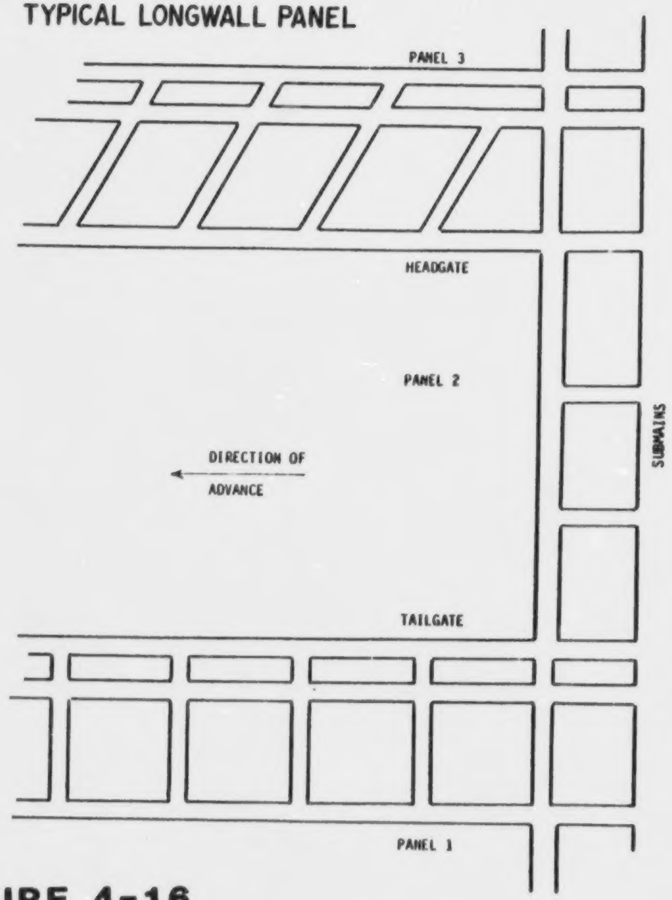

PANEL 3
HEADGATE
PANEL 2
DIRECTION OF
ADVANCE
SUBMAINS
TAILGATE
PANEL 1

FIGURE 4-16

EFFECT ON RECOVERY IN PANELS FOR DIFFERENT MINING SYSTEMS IN SAME MINE.

TYPICAL CONVENTIONAL PANEL. (D&B)	36%
TYPICAL DRUM MINER PANEL	28%
TYPICAL BORER MINER PANEL	23%
TYPICAL LONGWALL PANEL	81%

seam height along the face taking a cut of depth varying from 0.45 m to 0.61 m.

One of the major problems on the face is the considerable slabbing off of material that occurs due to seam height and ground pressures. The first cave follows immediately behind the shields as they advance and caves up least 10 metres, i.e. three times seam height. The second longwall panel is being mined alongside the first panel but separated by a 38 m wide pillar.

The ground is continually working under stress, and the face ahead of the machine and the pillars in the panel roadways at the ends of the face are constantly cracking as the pressure is working and assisting with the mining of the trona. As extraction increases, there is a notable increase in the strata pressures on the face and the roadway pillars that are being mined. It was evident in the roadways at the ends of the face adjacent to the old mined out panel that floor heave of between 0.6 and 1.0 metres was being encountered. The front abutment appears to be about 60 metres from the face line. The trona has a strength of between 50 and 60 Mpa and the longwall shearer normally produces between 4 and 7 shears per shift. The machine is working 12 full shifts per week with an ultimate target of 15 shifts per week. The mine normally works three 8 hour shifts per day with no takeoff on the face, but is currently introducing a four shift system whereby the shift times are staggered, so that the manpower for the longwall face takes over on the face.

Trona from the longwall face and in fact all other panels is removed on 1.2 m wide rope structure conveyors slung from the roof. All conveyors in the mine are controlled from a central monitoring station which can stop and start all conveyors in sequence and also has television monitoring of major transfer points.

The manpower on the longwall face comprises three machine men, (one at each end of the machine controlling the cutting horizon of each ranging drum, one man on the speed controls of the machine which normally cuts at a rate of 4.6 m per minute), one man in the main gate, two on chocks, and one man manually breaking lumps on the face. The conveyor in the main gate has a 150 metre belt storage unit and movements are made of all ancilliary equipment every 75 metres, corresponding to pillar centres; power is brought into the mine at 13,000 volts, transformed and distributed at 4160 volts to the panels, the longwall shearer and associated equipment is powered at 4160 volts, other equipment at 1000 volts.

The first 760 metre long panel took almost two years to mine because of problems with training, learning and also some equipment problems. The equipment was transferred from the first panel to the second panel which is 150 metres long. Operations in the second panel have been improved considerably and are approaching the levels at which the mine would consider the system acceptable. Typical performances over a recent three months have been that the 3.1 metre high 150 metre long excavation advanced 54, 42 and 70 metres per month respectively, totalling some 270,000 tonnes. Barrier pillars approximately 36 m by 38 m are left between adjacent panels and so far it has not been possible to determine the amount of subsidence on the surface due to longwall mining. Workings are approximately 500 metres deep and the trona bearing zone is overlain by a very thick sandstone some 90 metres above the No. 17 seam.

432 GEOTECHNICAL ASPECTS

The trona mine that was investigated in Wyoming was initially operated using a conventional room and pillar mining method with rooms between approximately 4.3 and 4.9 m wide and pillars of dimensions between approximately 10 and 27.5 m. The recoveries range up to 43%. More recently longwall mining was introduced along with the existing room and pillar mining to increase the recovery.

The room widths in the room and pillar areas are controlled by the stability of the back and a minimum of 450 mm of trona is left in place to ensure the stability of the overlying shales and the trona beds. The rooms are rock bolted on a regular pattern of approximately 1.2 m using resin grouted bolts. Attempts have been made to pillar mining certain areas but ground stability was so poor that these attempts were subsequently abandoned. Gas is present in the shales in the roof of the mines and pressure relief holes are drilled into the shales to prevent roof collapse. Some spalling of the edge of pillars is experienced although this does not represent a significant stability program.

Support conditions throughout the mine varied considerably. In certain areas of the mine, particularly in the northeast where conditions are considerably weaker, 3.1 m straps are also bolted across the roadways. In addition in ripper head miner roadways because of the vertical sides it was found necessary to put in one side bolt every 3.1 metres. It was noticeable in roadways which had been bored by the rotary miner that spalling started at a point approximately one third up the cusp from the floor and seemed to correlate to a major clay band in the seam.

The rotor miners are normally used for driving roadways since the shape that they produce with curved corners at the tops of the roadways does provide better support. In rotor mined roadways only three lines of 1.5 m resin bolts are set on 1.2 m centres whereas in main roadways produced by the ripper miners which are of rectangular section five lines of bolts have to be placed to maintain the same standard of roof control.

Although certain start up difficulties have been experienced with longwall mining, these are not directly attributed to geotechnical problems. High stresses are evident at the face and at the edge of the roadway pillars, and floor heave of up to one metre is evident in some of the roadways. However, there are more operational concerns than major stability problems. Cable bolts are used in some roadways for the longwall panel to maintain stability, these being approximately 2.4 m long. Wooden chocks in the two tailgate roadways are also used to control floor heave and roof stability ahead of the face. Initial caving of the roof occurs immediately behind the shields and caves up at least 10 m. i.e. three times seam height. It is not known where the next cave occurs or how high it goes but on the second panel two holes have been drilled from the surface and instrumented with equipment set at different levels up from the seam so that an assessment can be made of the rates of convergence and the stresses in the rock above the panel and the height to which the cave goes. The second longwall panel is being mined alongside the first panel but separated by a 38 m wide pillar.

This trona mine in Wyoming demonstrates quite clearly difficulties that are experieced in increasing extraction using room and pillar mining methods when the quality of the rock in the roof is poor. In this case, it was found that extraction could be increased using a longwall caving mining method.

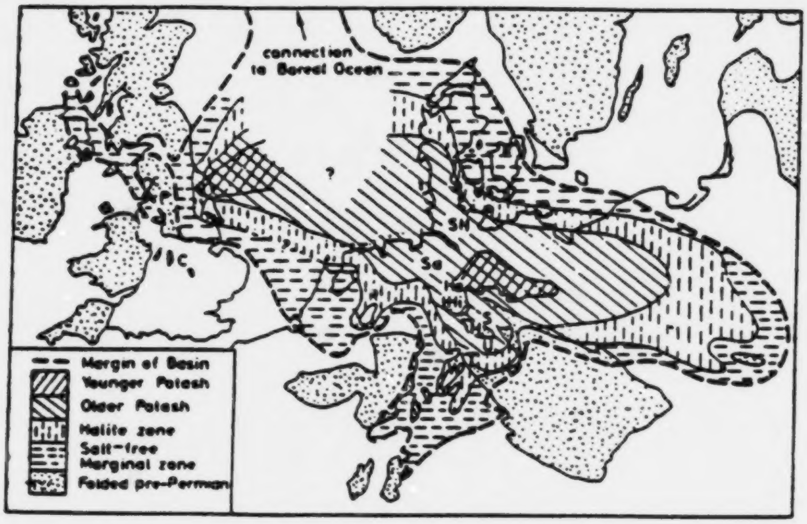
4.4 WEST GERMANY (German Federal Republic)

441 GEOLOGICAL ASPECTS

The Zechstein Basin developed over most of Denmark, Poland, northern England, Germany, and the Netherlands during the latter of part of the Permian (see Figure 4-17). Five major evaporite cycles were deposited in subbasins behind a series of bar zones which restricted connection to the open sea to the north (see Figure 4-18). Stratigraphic sections are most commonly referenced to the German portion of the basin. The lowermost cycle, the Zechstein 1 or Werra Series, includes the Thüringen and overlying Hessen potash zones. Typically, the Thüringen seam is sylvinitic (with some kieserite) but may be almost entirely carnallitic in places. The Hessen seam contains halite, kieserite, and sylvite (hartsaltz) where commercially exploited. Both seams normally vary between 2 and 3 metres in thickness. The Zechstein 2 cycle included deposition of the Strassfurt seam which has kieserite-sylvite or kieserite-carnallite potash mineral assemblages. The entire interval of mineralization may be as much as 40 m thick.

The Ronnenberg and Riedel seams formed during the Zechstein 3 cycle (Leine Series). These potash beds are generally sylvinitic. Thicknesses of 6 to 10 m have been recorded for the lowermost or Ronnenberg seam and the overlying Riedel unit may vary in thickness between 3 and 5 m.

Considerable disturbance of salt beds has taken place in the Zechstein basin. Salt domes, pillows, and elongated walls are common structural features, particularly in the deeper parts of the basin. Table 4-2 illustrates the geological characteristics of West Germany's Potash Mines.


connection
to Boreal Ocean
?
SH
Sa
C
Hi
S
Margin of Basin
Younger Potash
Older Potash
Halite zone
Salt-free
Marginal zone
Folded pre-Permian

Note that the Older Potash of England may be equivalent to the Younger Potash of Germany. C = Central England Stable Block; P = Pennines; Y = Yorkshire; R = Lower Rhine Basin; Sa = Lower Saxony Basin; SH = Schleswig-Holstein; Ha = Hannover; Hi = Hildesia; S = Stassfurt; H = Harz Mountains; U = Unstrut district; W = Werra-Fulda Basin; T = Thüringer Wald.

FIGURE 4-17 REGIONAL GEOLOGY ZECHSTEIN BASIN

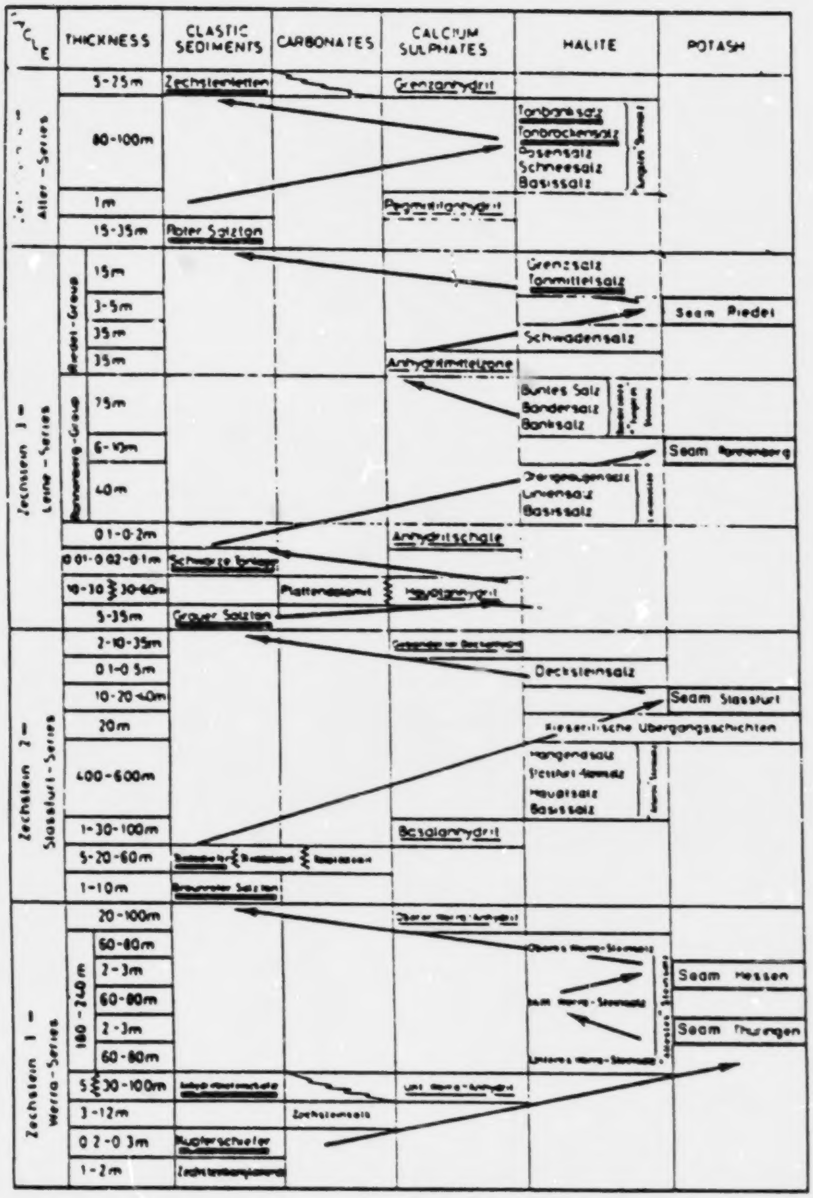

CYCLE
THICKNESS
CLASTIC SEDIMENTS
CARBONATES
CALCIUM SULPHATES
HALITE
POTASH
Aller - Series
5-25m
Zechsteinletten
Grenzanhydrit
80-100m
Tonbanksalz
Tonbrockensalz
Rosensalz
Schneesalz
Basissalz
1m
Pegmatitanhydrit
15-35m
Roter Salzton
Zechstein 3 - Leine - Series
Riedel-Gruppe
Ronnenberg-Gruppe
15m
Grenzsalz
Tonmittelsalz
3-5m
Seam Riedel
35m
Schwadensalz
35m
Anhydritmittelzone
25m
Buntes Salz
Bandersalz
Banksalz
6-10m
Seam Ronnenberg
40m
Liniensalz
Basissalz
0.1-0.2m
Anhydritschale
0.01-0.02-0.1m
Schwarze Tonlage
10-30 30-60m
Plattendolomit
Hauptanhydrit
5-35m
Grauer Salzton
Zechstein 2 - Stassfurt - Series
2-10-35m
0.1-0.5m
Decksteinsalz
10-20-40m
Seam Stassfurt
20m
Kieseritische Übergangsschichten
400-600m
Hangendsalz
Hauptsalz
Basissalz
1-30-100m
Basalanhydrit
5-20-60m
1-10m
Braunroter Salzton
Zechstein 1 - Werra - Series
20-100m
180-240m
60-80m
2-3m
Seam Hessen
60-80m
Werra-Steinsalz
2-3m
Seam Thuringen
60-80m
5 30-100m
3-12m
Zechsteinkalk
0.2-0.3m
Kupferschiefer
1-2m
Zechsteinkonglomerat

FIGURE 4-18 STANDARD ZECHSTEIN SUCCESSION SHOWING VARIATIONS IN BRINE CONCENTRATION DURING FORMATION OF CYCLES

TABLE 4-2

West Germany (German Federal Republic) Geological Characteristics of Potash Mines

Mine	Potash Zone	Depth in Metres	Dip in degrees	Ore Types	Mining thickness (m)	K_2O%
All mines controlled by Kali und Salz A.G.						
Wintershall,	Thüringen	540	2°-3° SW	hartsalz Carn.	2.5 - 3.5	11
	Hessen			hartsalz	8 - 9	
Hattorf	Thüringen	760 1 040	2° - 3° SW	hartsalz, carn.		12 - 13
	Hessen	700 - 1 000		hartsalz, carn.	1.5 - 3	10
Neuhof-Ellers	Hessen	600	2° - 3° SW	hartsalz	2	12
Niedersachsen - Riedel	Riedel	750 - 1 320	33° - 90°	sylvinitic	2 - 3.5	14.1
Bergmannssegen - Hugo		350 - 1 180	40° - 90°	hartsalz		12
Salzdetfurth	Ronnenberg	774 - 900	40° - 90°	sylvinite carn.	6 - 8 up to 30	12
Siegfried - Giesen	Ronnenberg	774 - 1 050	40° - 90°	sylvinite carn.	6 - 8 up to 30	11
Sigmundshall	Ronnenberg	725 - 1 040	44° - 90°	sylvinite	4 - 30	17 - 20

442 MINING ASPECTS

Gemany was the first country to produce potash by underground mining. This was begun in 1856.

There are two mineralized areas producing potash, one in the northern Hannover area and one in southern Werra district. Geological conditions vary widely between the northern and southern districts and in this regard different mining methods are now employed to extract the ore.

Kali und Salz AG now control the eight operating potash mines in West Germany: five in the northern area and three in the southern (see Figure 4-19).

The southern deposits located between the Werra and Fulda rivers have easily-accessible level deposits but with thin seams (1.3-3.5 m) and K_2O contents in the range of 7-15%. These southern deposits average 3.5% K_2O less than the northern deposits. The seam gradients dip at 2° or 3° to the southwest. There are two main seams: Hessen (1.3-3.5 m), Thüringen (1.5-3.0 m) and an additional seam, the Leader (0.1-10.0 m) which is associated with the Hessen seam, is occasionally mined.

The mining method in the southern area is by room and pillar using drilling and blasting techniques. Transport of the ore is by LHDs and belt conveyors (Figure 4-20).

The northern evaporite deposits have been severely folded and faulted and the beds of potash dip steeply (between 40° and 90°) (see Figure 4-21). The K_2O content of the ore is about 13-14% K_2O. There are three seams: Riedel, Ronnenburg and Strassfurt and the seams can vary between 4 and 30 m.

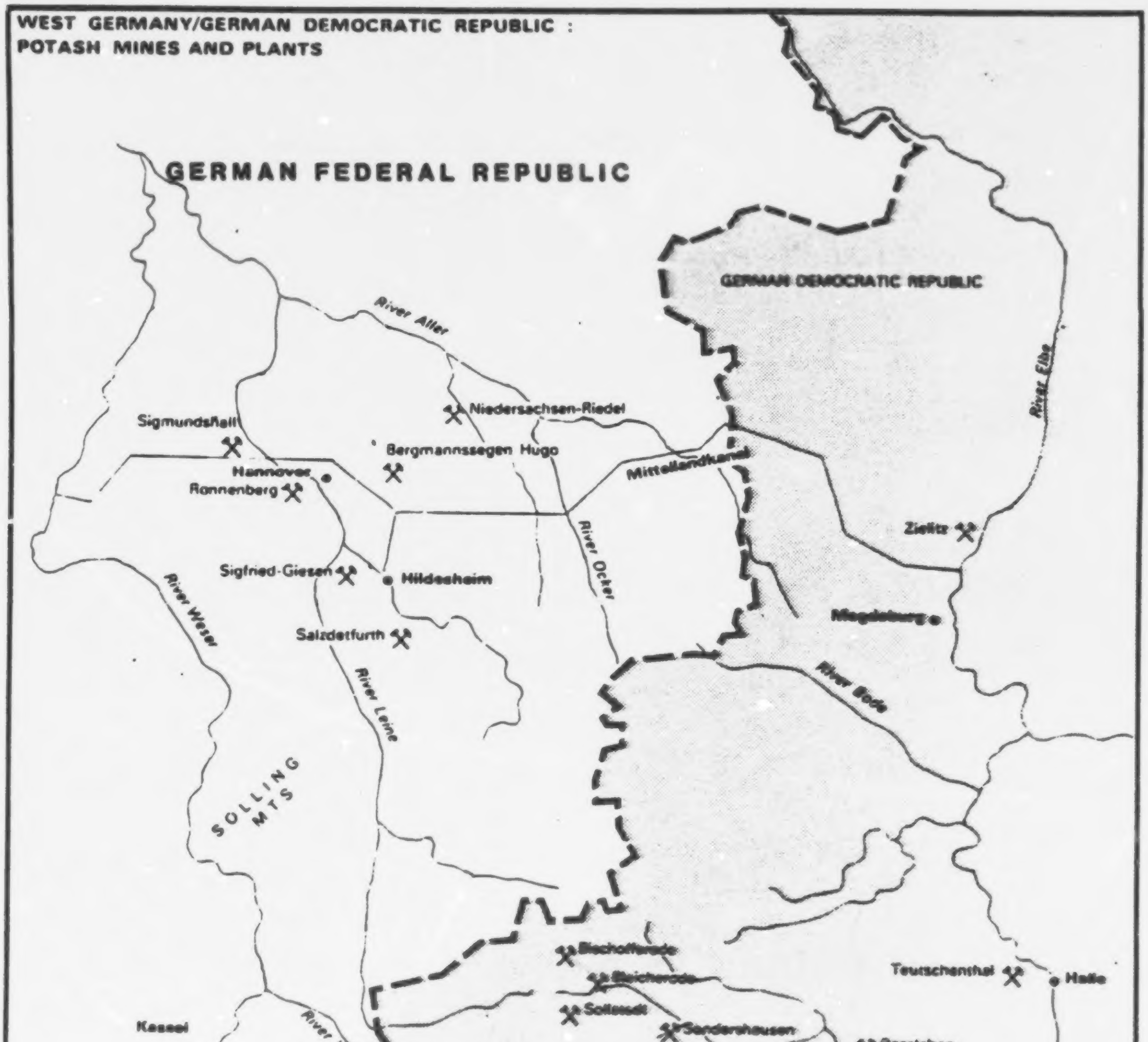

WEST GERMANY/GERMAN DEMOCRATIC REPUBLIC :
POTASH MINES AND PLANTS
GERMAN FEDERAL REPUBLIC
GERMAN DEMOCRATIC REPUBLIC
River Aller
River Elbe
Niedersachsen-Riedel
Sigmundshall
Bergmannssegen Hugo
Hannover
Ronnenberg
Mittellandkanal
Zielitz
River Oker
Sigfried-Giesen
Hildesheim
River Weser
Magdeburg
Salzdetfurth
River Leine
River Bode
SOLLING MTS
Bischofferode
Bleicherode
Teutschenthal
Halle
Sollstedt
Kassel
Sondershausen
Rossleben
River Werra
Menterode
River Unstrut
River Fulda
Eisenach
Wintershall
Hattorf
Kalibetrieb Werra
N
Neuhof Ellers
0
50 km

FIGURE 4-19 LOCATION OF POTASH MINES - WEST GERMANY

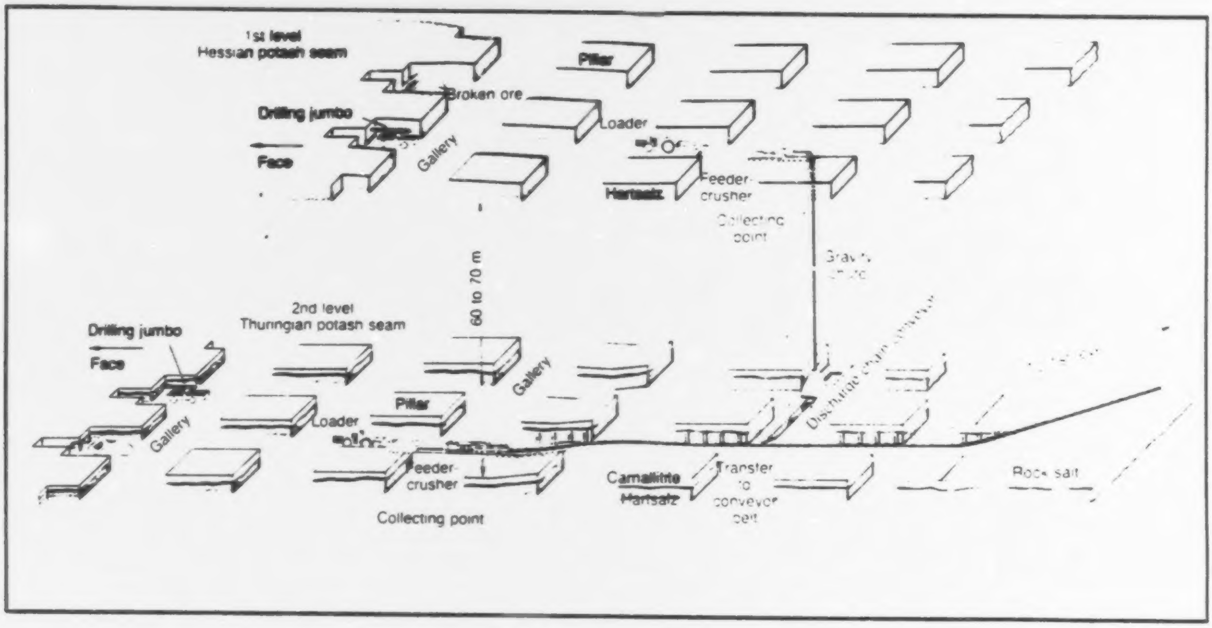

1st level
Hessian potash seam
Pillar
Broken ore
Drilling jumbo
Face
Gallery
Loader
Hartsalz
Feeder-crusher
Collecting point
Gravity chute
60 to 70 m
2nd level
Thuringian potash seam
Drilling jumbo
Face
Gallery
Pillar
Loader
Gallery
Feeder-crusher
Collecting point
Discharge chain conveyor
Carnallitite
Hartsalz
Transfer to conveyor belt
Rock salt

FIGURE 4-20 TYPICAL CONVENTIONAL ROOM & PILLAR MINING SIMULTANEOUSLY IN TWO SEAMS

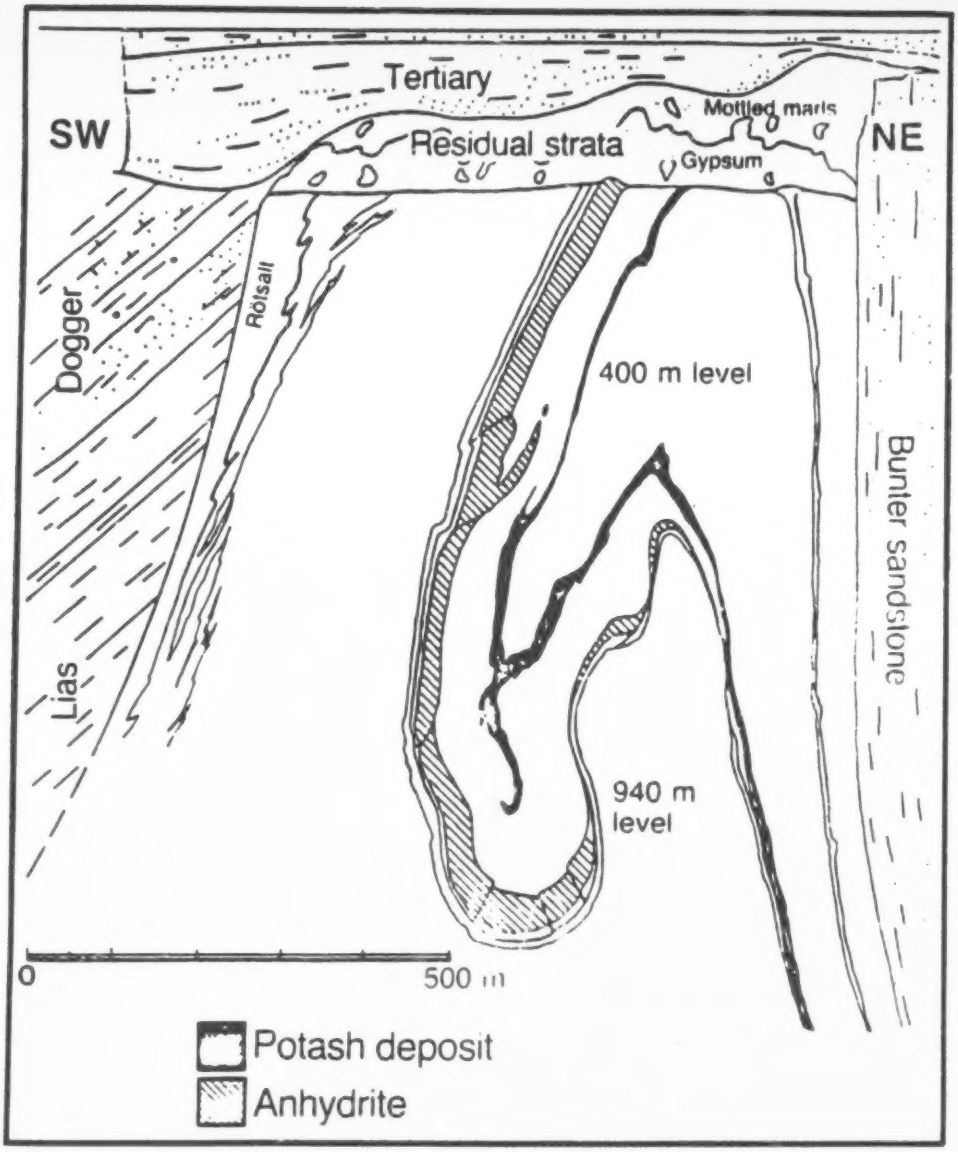

Tertiary
Mottled marls
SW
Residual strata
Gypsum
NE
Dogger
Rötsall
400 m level
Bunter sandstone
Lias
940 m level
0
500 m
Potash deposit
Anhydrite

FIGURE 4-21 GEOLOGICAL SECTION NORTHERN REGION - WEST GERMANY

The northern area is faced with more difficulties than the southern because of longer haulage distances, higher rock temperatures as mines are deep due to the dip, and backfill operations required to control subsidence. The general mining advance tends to be vertical rather than horizontal.

The extraction of potash in the salt domes in the northern area has led to the development of the open sublevel stoping method which is briefly described below.

At least two vertical shafts have been sunk into the salt body adjacent to the ore deposit. The salt body is vertically subdivided by main levels of either 200 or 250 m. Exploration for potash is conducted from the lowest level. The drilling not only defines the ore body but locates pockets of dangerous gas and brines.

In developing the mining sequence a spiral ramp which has a gradient of 15% is driven parallel to the potash beds. Sublevel entries are driven from the spiral ramp to the limits of the stope panel. The stope panels are about 200 m high and several hundred metres long. A single stope in a panel is 100 m long. The spiral ramp and sublevel stoping are shown on Figure 4-22. The stope panel is supported by pillars 6-12 m long dividing the panel into stopes.

The entries and sublevels are driven by using blast hole jumbos. These jumbos drill holes 7 m in length and 40 cm in diameter for centre holes and smaller diameter holes parallel to the centre at speeds from 8 to 14 m per minute. Waste salt is transported as backfill to empty stopes by LHD's. ANFO is used as the blasting agent and is delivered from surface to the level by pipes in the shaft.

The next stage is developing funnels (cones) between the lower main level up to sublevel 1. A raise has been drilled at 0.7-1.0 m

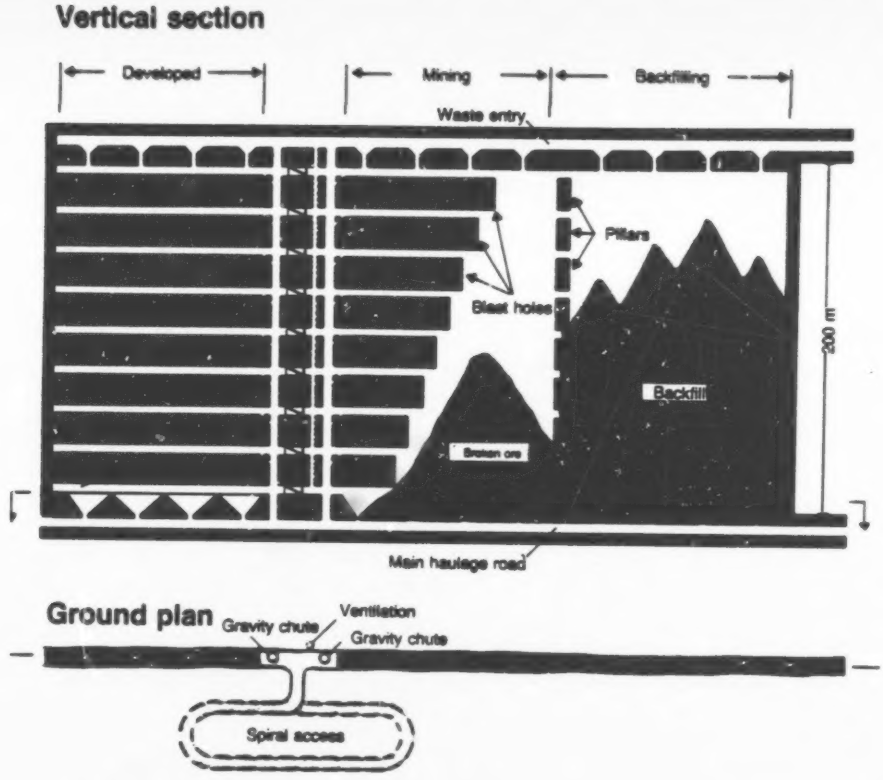

Vertical section
Developed
Mining
Backfilling
Waste entry
Pillars
Blast holes
200 m
Backfill
Broken ore
Main haulage road
Ground plan
Gravity chute
Ventilation
Gravity chute
Spiral access

FIGURE 4-22 DIFFERENT STAGES OF FUNNEL STOPING: DEVELOPMENT, MINING, BACKFILLING

diameter between sublevels at one end. The raise is next enlarged. The lower bench is then drilled and blasted in a sequence. Benches higher up are drilled and blasted but the lower bench blasting always precedes the bench higher up.

The ore is directed via gravity chutes into mine cars and also loaders. The new mine car system is the Grangesberg system which comprises 20 cars at 30 t each. The system is automatic with overlapping cars so that loading is continuous. It has a bottom discharge system. Scoop trams of 8-15 t also transport ore to crushers which in turn feed conveyor belts.

When the ore reaches the bottom of the shaft it is hoisted directly to surface or it is placed in large underground storage bins which have a capacity in some cases of 100 000 t.

After the stopes are emptied, tailings and underground waste are conveyed to stope by either belt conveyors or mine trains and dumped at the upper main level into the stopes.

The typical northern area mine transports 10 000 t of raw ore, 1 300 t of waste rock, 5 000 t of tailings from the refinery; thus, 16 300 t of solid material and in addition 150-200 m^3 of brine from filled stopes.

The maintenance areas for the mine equipment are located in large excavations underground.

The productivity is about 45 t per manshift at a typical mine in the northern area.

The average airflow of these mines is around 25 000 m^3/min which results in a bearable climate. Hot air from deep workings is exhausted through drilled raises to avoid increasing the working area's temperature.

Kali und Salz are investigating continuous miners for developing headings and sublevels.

443 GEOTECHNICAL ASPECTS

Potash is mined in West Germany from both bedded deposits and salt domes. Information was unavailable related to geotechnical aspects of mining bedded deposits.

The salt dome deposits are steeply dipping and all mined by sublevel open stoping methods down to depths of 1300 to 1400 m. The extraction is quite high, 85 per cent or more, and the stopes are backfilled with waste salt and tailings. The stopes are quite large being typically 200 m high and 100 m long. The hanging wall of the stopes consists of 150 m or more of evaporites and hence is quite competent. The backfill prevents massive caving of the hanging wall.

The backs of the development drifts are usually arched to improve stability and sublevel entries are up to 30 m wide. High air quantities are used for ventilation and this cools the rock at deep depths which in turn improves stability. Most openings do not have rock bolts or other forms of support.

4.5 EAST GERMANY (German Democratic Republic)

451 GEOLOGICAL ASPECTS

The regional geology for East Germany is the same as West Germany. For continuity it is repeated.

The Zechstein Basin developed over most of Denmark, Poland, northern England, Germany, and the Netherlands during the latter part of the Permian (see Figure 4-17). Five major evaporite cycles were deposited in subbasins behind a series of bar zones which restricted connection to the open sea to the north (see Figure 4-18). Stratigraphic sections are most commonly referenced to the German portion of the basin. The lowermost cycle, the Zechstein 1 or Werra Series, includes the Thüringen and overlying Hessen potash zones. Typically, the Thüringen seam is sylvinitic (with some kieserite) but may be almost entirely carnallitic in places. The Hessen seam contains halite, kieserite, and sylvite (hartsaltz) where commercially exploited. Both seams normally vary between 2 and 3 m in thickness. The Zechstein 2 cycle included deposition of the Strassfurt seam which has kieserite-sylvite or kieserite-carnallite potash mineral assemblages. The entire interval of mineralization may be as much as 40 m thick.

The Ronnenberg and Riedel seams formed during the Zechstein 3 cycle (Leine Series). These potash beds are generally sylvinitic. Thicknesses of 6 to 10 m have been recorded for the lowermost or Ronnenberg seam and the overlying Riedel unit may vary in thickness between 3 and 5 m.

Considerable disturbance of salt beds has taken place in Zechstein basin. Salt domes, pillows, and elongated walls are common structural features, particularly in the deeper parts of the basin.

TABLE 4-3

EAST GERMANY (German Democratic Republic)
Geological Characteristics of Potash Mines

Mine	Potash Zone	Depth in Metres	Dip in Degrees	Ore Type	Mining Thickness in Metres	%K_2O
Kalibetrieb Werra	Hessen	300-1000		Kieseritic Hartsalz		
- Unterbriezbach						
- Merkers	Thüringen	700	2°-32°	Carnallite		
- Dorndorf				Sylvite		
Kalibetrieb Süd Harz						
- Rossleban (Heinrich Raun)		700		Hartsalz	13-14	
- Sondershausen (Glückauf)		659-793				
- Sollstedt (Karl Marx)		570-721				
- Bleichrode (Karl Liebnecht)		628-657				
- Volkenrode		1000-1033				
- Bischofferode (Thomas Münzer)		628-657				
Kali-Und Steinsalzbetrieb Saale						
- Teutschental		733-888				
Kalibetrieb Zielitz						
- Zielitz	Ronnenburg	700-1000	17°-23°	Sylvinite	6-9	15

Table 4-3 illustrates the geological characteristics of East Germany's potash mining.

452 MINING ASPECTS

The potash mining industry of East Germany is the third largest in the world in terms of production. Only the USSR and Canada produce larger quantities.

Production was begun in the mid 19th century. In January 1970 the East German potash industry was reorganized into four mining groups operating 11 multi-shaft mines (see Figure 4-23). Mining is by the traditional drill and blast technique using the room and pillar system with an extraction rate of around 50 percent. East German potash production was 3.45 million tonnes of K_2O in 1981. The groups and mines are listed on Table 4-3.

The newest mine, Zielitz, which began production in 1973 was prepared to exploit the Calvorde block and is the northernmost mine in East Germany. The Ronnenberg potash bed which is mined, dips evenly at an angle between 18° to 25° and is encountered at depths ranging from 700 m to over 1000 m. The bed varies between 4 and 6 m in thickness and is overlain by rock salt and carnallite.

The mine has two shafts: No. 1 shaft which is 806 m deep and 7.5 m in diameter is equipped with two 50 t skips and operates at 15 m/s; No. 2 shaft is 741 m deep and is used to transport personnel and equipment.

The mining method is a room and pillar system using a drilling and blasting technique to mine the ore. Dimensions of the room and pillar vary depending on ground conditions; but about 50 percent of the

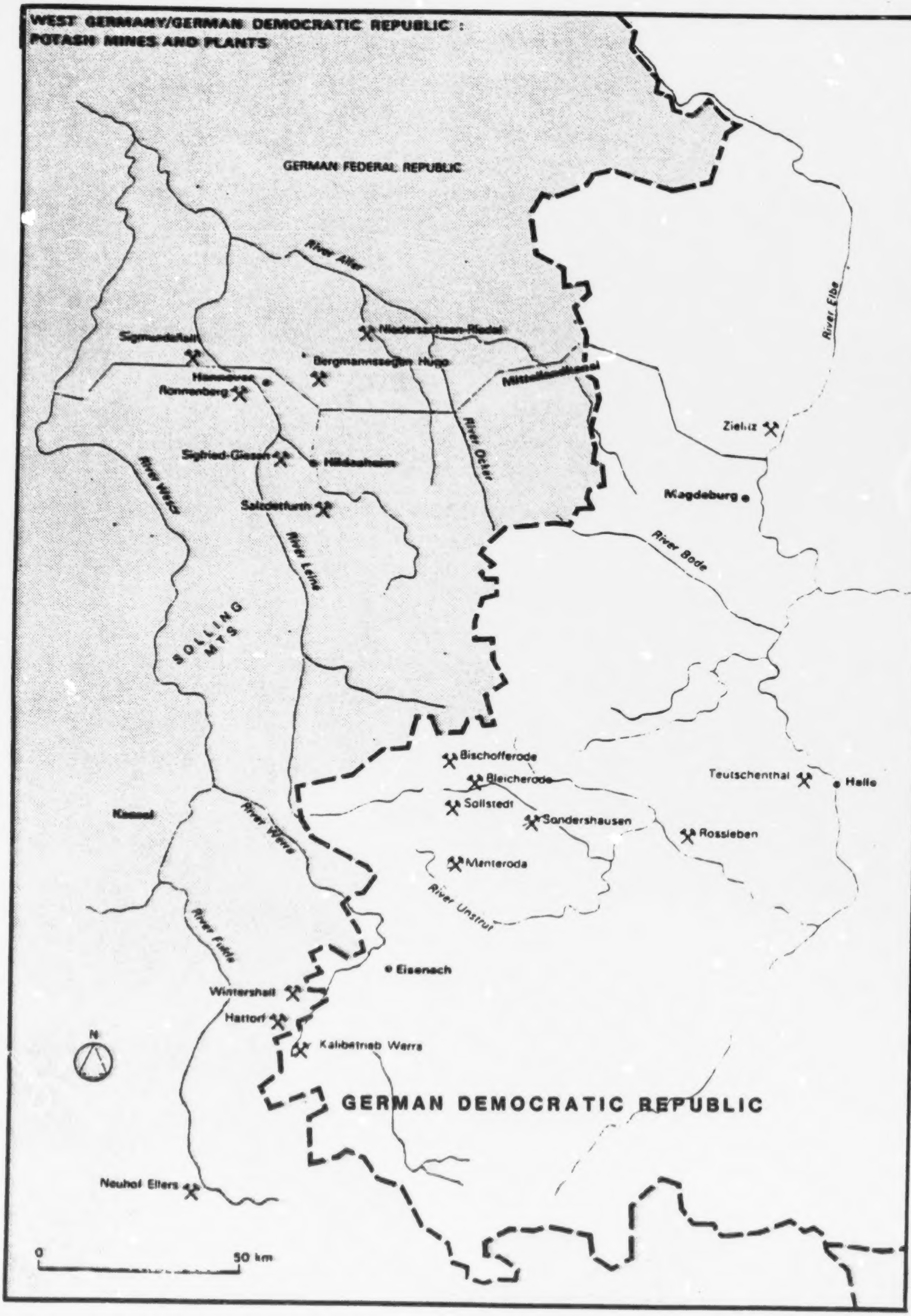

WEST GERMANY/GERMAN DEMOCRATIC REPUBLIC :
POTASH MINES AND PLANTS
GERMAN FEDERAL REPUBLIC
River Aller
Niedersachsen-Riedel
Sigmundshall
Bergmannssegen Hugo
Hannover
Ronnenberg
Mittellandkanal
River Oker
Zielitz
Siegfried-Giesen
Hildesheim
River Weser
Salzdetfurth
Magdeburg
River Bode
River Leine
River Elbe
SOLLING MTS
Bischofferode
Bleicherode
Sollstedt
Sondershausen
Teutschenthal
Halle
Rossleben
Kassel
River Werra
Menteroda
River Unstrut
River Fulda
Eisenach
Wintershall
Hattorf
Kalibetrieb Werra
N
GERMAN DEMOCRATIC REPUBLIC
Neuhof Ellers
0
50 km

FIGURE 4-23 LOCATION OF POTASH MINES - EAST GERMANY

ore is extracted. The face is drilled by large diameter holes which is then encircled by small diameter holes which are blasted. Blasting is carried out during shift change for safety reasons. The ore is removed by 8 t scoop trams which transport the potash to a collection point not further than 300 m from the working face. Crushers then break the ore to 250 mm. The conveyor transports the potash to the No. 1 shaft where two intermediate bins of storage capacity of 2000 and 20 000 t hold the ore until it is removed to two 50 t bunkers for immediate loading onto the skips. Twenty thousand tonnes can be raised to surface in 18 hours.

After the ore is removed from the working face the roof is supported by roof bolts which are installed automatically.

In the southern district, GDR Werra potash mining district, mining is somewhat different from that in the northern district. The southern district which has a high degree of carnallite is characterized by strongly varying seam thickness, low rock strength with the ever present danger of salt and gas outburst.

A modified room and pillar mining system working in two phases is employed.

The potash deposit of the Werra Mining district consists of two potash seams: the lower Thüringen seam and the upper Hessen seam. Mainly the seams are flat lying but in some areas have been subjected to tectonic stress. The overlying rock is penetrated by fault fractures with large separation and also include basalt intrusions.

The overlying rock has had large quantities of potash waste liquors injected into it from surface and the intact rock has been dislocated by leaching depression which has removed the salt. The impregnation of the overlying rock by basalts in Miocene times has also included large quantities of carbon dioxide.

As stated previously the mining of the carnallite in the Thüringen seam is carried out in two phases. In the first phase, the faces are mined at a reduced cross section with pillars being larger than required. In the second phase the stopes are widened horizontally and may also be increased in a vertical direction until the pillars are at their full load-bearing capacity.

In the first phase drifts are driven at the seam base. In the second phase the drifts are funneled upward (see Figure 4-24). The dimensions of the funnels are at a maximum of 6 m wide at the base, and 25 metres at their full height of 35 metres. The thickness and extent of the dome flanks are also explored from the drifts.

Because of the danger of salt and gas bursts, only drilling and blasting can be used for breaking the potash. Blasting is done at shift change when the crews have withdrawn from the working area.

Large hole drills and blast hole drill jumbos are used as well as machines for loading explosives. Test holes are drilled for investigation. Possible gas emissions can be identified with a special well packer. If gas emissions are indicated, the drill carriages can be operated by radio control. Mechanical scaling is used for removing loose material from the backs and sides. Rock bolts are used for drift support.

The funnel openings as shown on Figure 4-24 are produced by drilling long holes in the roof and upper parts of the sidewall. Five to seven holes are drilled per round and the length of the shot can be up to 2.5 m using blasting cartridges. Scoop trams haul the potash from the face to breakers which then feed the conveyor. Mucking and

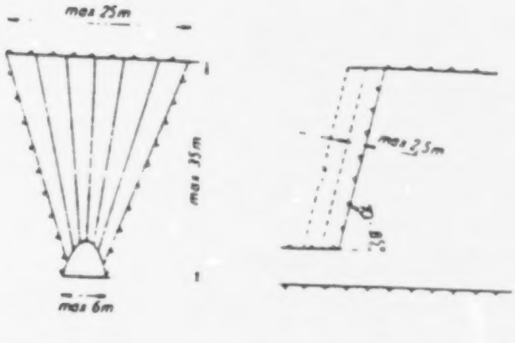

max 25m
max 35m
max 6m
max 2,5m
85°

FIGURE 4-24 DRILL PATTERN FOR THE FUNNEL TYPE WIDENING OF THE ROOM

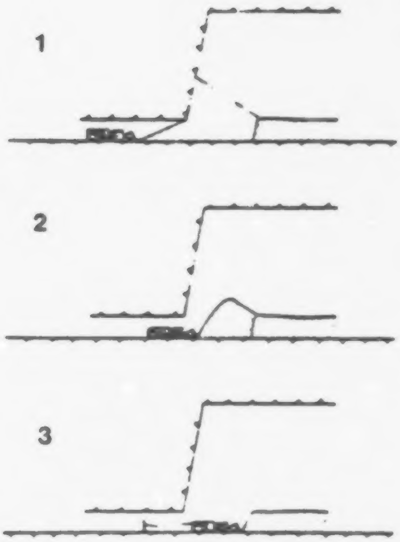


FIGURE 4-25 MUCKING AND HAULING OF A ROUND FROM THE BACK OF STOPE IN THREE STEPS

hauling is done in three stages; in the first stage, the potash in the drift is removed and hauled; in the second stage, the loading and hauling of potash immediately adjacent to the heading edge is carried out as shown in Figure 4-25, the driver working under the protected back of the drift; and in the third stage the potash is gathered using cable operated remote control equipment thus protecting the driver.

453 GEOTECHNICAL ASPECTS

Potash mining is undertaken in a number of mines in East Germany in the three main districts of Werra River, Sudharz, and Calvarde. The depth of the potash deposits ranges between 300 m and 1200 m below surface. The potash deposits are relatively flat dipping, and individual seams range in thickness from 2 to 10 m with localized domes being up to 40 m thick.

Geological conditions vary between the three districts and this has had an impact on some of the specific geotechnical aspects associated with underground mining, although most mining is undertaken with room and pillar mining system including pillar mining in some cases. Longwall mining has been investigated to increase extraction and improve ventilation but it is understood that this method has not been implemented, probably because of the danger of gas bursts.

Roof conditions in the various mines vary from salt of over 100 m thickness to thinner salt, salty clay and anhydrite seams. Many of the deposits contain carbon dioxide which results in outbursts of salt and gas when mined. Because of this, all excavation is by drill and blast methods and mechanical excavation is not used. Some areas are overlain by natural aquifers or by horizons in which waste salt liquids have been disposed by injection. Conservative mining approaches are adopted where impermeable barriers between overlying aquifers and the mining seam cannot be guaranteed.

Room and pillar mining with long term stable pillars is used in many of the mines, using either a single or double pass system. In the double pass system, the width and/or the height of the rooms is increased during the second pass. Initially the mining involved long room and pillars, although this has subsequently been changed to short or square pillars. In the two pass system, the maximum mined thickness is generally 5 m, and the size of the final room after the second pass is determined from the geological conditions observed during the first pass.

Mining of thick seams is sometimes carried out by driving a 6 m opening at the base of the deposit, arching the back of the opening to improve stability. After this drift has been completed, a trough typically 25 m high, 25 m wide at the top and 6 m wide at the bottom is mined by drilling and blasting up from the initial 6 m opening. This mining is done on a 44 m to 48 m square pattern.

Pillar mining is carried out in some room and pillar mines, with the remaining pillar stubs crushing and failing as the working front retreats from the far extremity of the mine. This type of mining is restricted to areas where the overlying hydrological conditions are favourable. The pillar mining is associated with significant subsidence on surface. Extraction ratios of up to 50 percent have been achieved with pillar mining compared with 30 percent in the stable pillar areas. It is understood that backfilling is not undertaken on a routine basis.

Empirical relationships based on the strength of the potash, the height to width ratio, the percentage carnallite content in the potash, and the length of time the pilllars need to remain stable have been developed at the mines. Barrier pillars of 120 m width are left at intervals of 500 m between working panels. Rock bolts are installed in the openings on a random as required basis.

It is reported that a major collapse of an underground mine in the Werra district occurred approximately 25 years ago. This was attributed to a large number of pillars becoming overloaded and failing in a sudden catastrophic manner.

4.6 UNITED KINGDOM

461 GEOLOGICAL ASPECTS

Boulby Mine is located on the northeast coast of England, close to the boundary between Cleveland and North Yorkshire (Figure 4-26). Since 1973 Cleveland Potash Ld. has been extracting potash from the complex sub-horizontal zone of chloride minerals of the third Zechstein cycle (EZ3) more than 1000 m below sea level at Boulby (Figure 4-27).

Exploration cores from the chloride layers of the mine area displayed nearly horizontal foliations. Such foliations were approximately parallel to the regional dip of the enclosing sediments (about 2° to the SE). Nonetheless, the mine was planned on the reasonable assumption that development would be in essentially undeformed sediments with only local, fault induced, complications. As mining progressed it became increasingly obvious that the near seam lithologies had suffered extensive mobilization by both chemical and physical processes at some unknown time or times in the past. Extensive folds and thrusts repeat the potash ore horizon in vertical section in various parts of the mine and such structures affect the economics (and safety) of the mining operation.

Figure 4-28 illustrates the near seam stratigraphic succession near the two shafts at Boulby Mine. This general succession is thought to be essentially continuous across the whole of the Cleveland Potash Ltd. concession area and is known to extend considerably further east beneath the North Sea where the potash units reach thicknesses in excess of 40 m.

The Boulby Potash is about 1100 m below sea-level (1170 m below surface) at the two shafts and the overlying evaporite sequence of

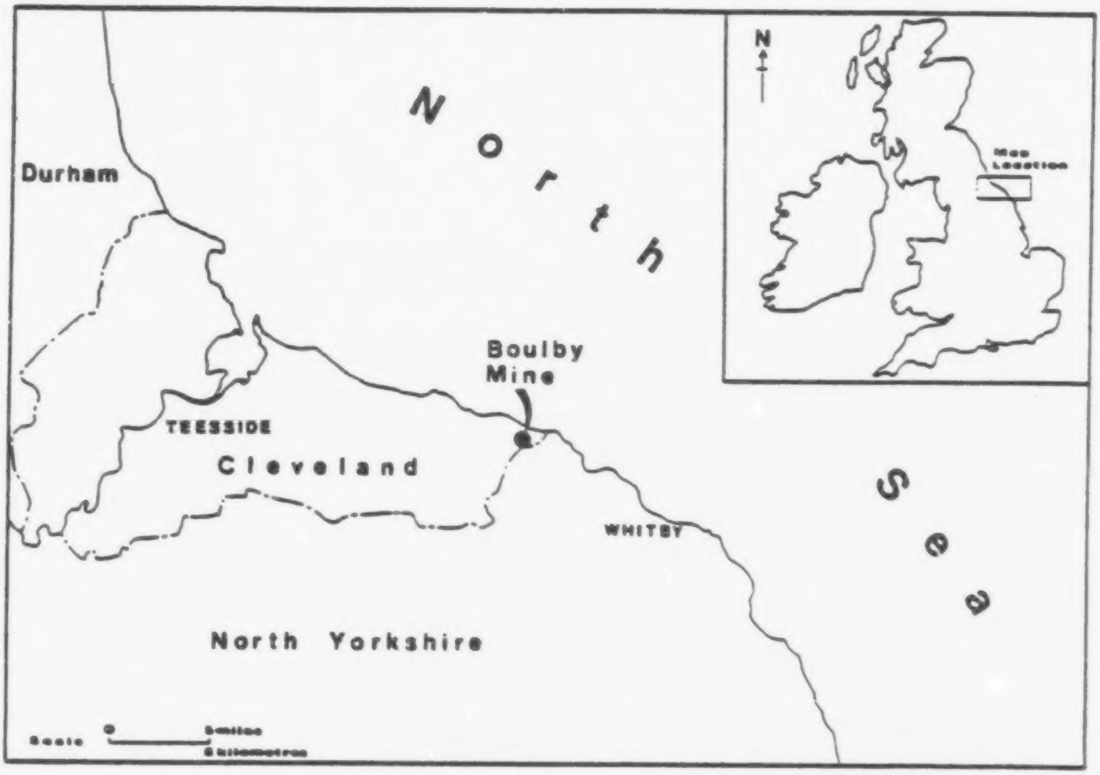
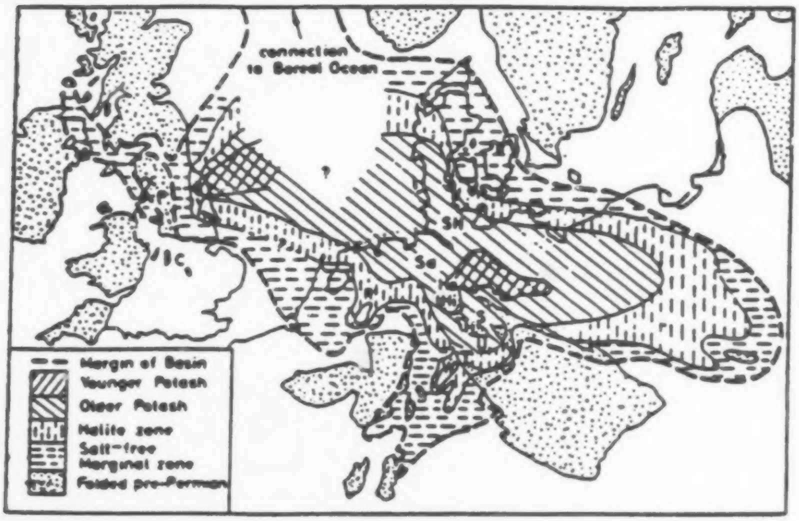

North Sea
Durham
Boulby Mine
TEESSIDE
Cleveland
WHITBY
North Yorkshire
Scale 0 5 miles
8 kilometres
N
Map Location

FIGURE 4 -26 LOCATION OF POTASH MINE - UNITED KINGDOM

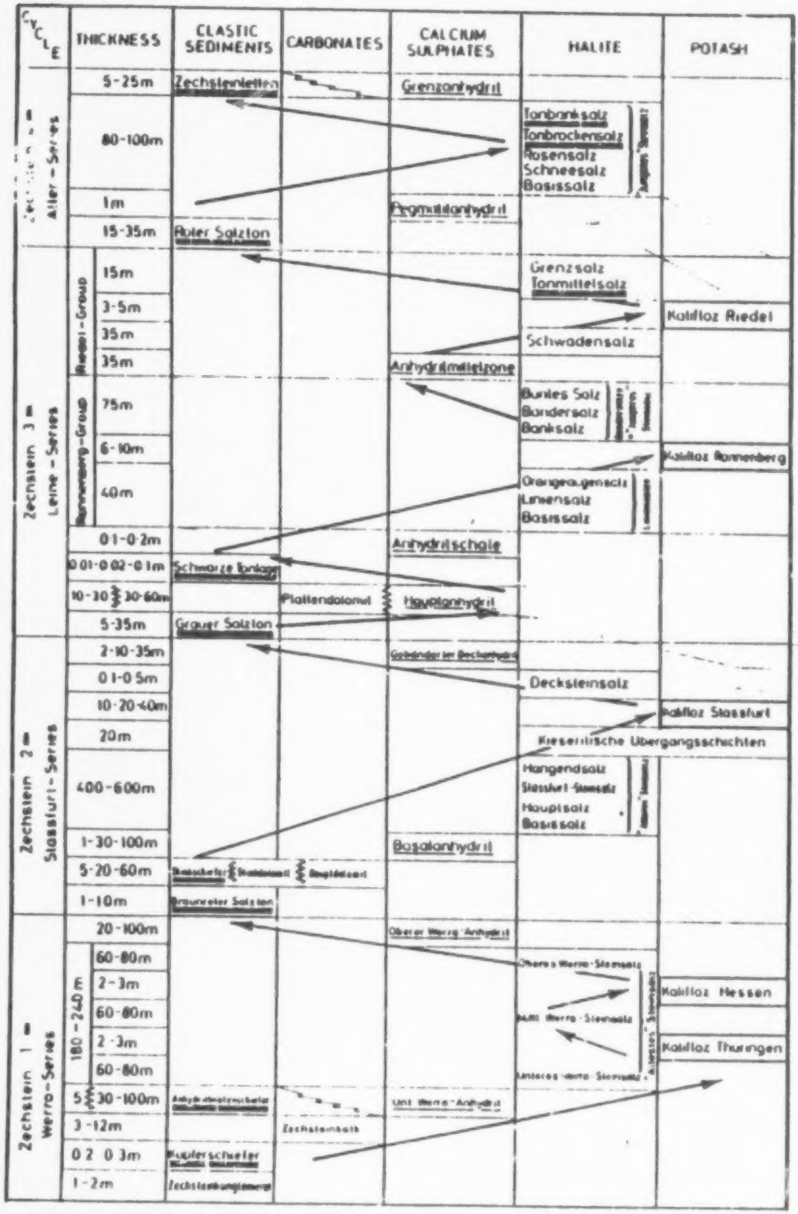

connection
to Boreal Ocean
?
SH
Sa
C
Margin of Basin
Younger Potash
Older Potash
Halite zone
Salt-free
Marginal zone
Folded pre-Permian

Note that the Older Potash of England may be equivalent to the Younger Potash of Germany. C = Central England Stable Block; P = Pennines; Y = Yorkshire; R = Lower Rhine Basin; Sa = Lower Saxony Basin; SH = Schleswig-Holstein; Ha = Hannover; HH = Hildesia; S = Stassfurt; H = Harz Mountains; U = Unstrut district; W = Werra-Fulda Basin; T = Thüringer Wald.

FIGURE 4-27 REGIONAL GEOLOGY ZECHSTEIN BASIN

FIGURE 4-28

STANDARD ZECHSTEIN SUCCESSION AND NEAR SEAM GEOLOGY - UNITED KINGDOM


CYCLE
THICKNESS
CLASTIC SEDIMENTS
CARBONATES
CALCIUM SULPHATES
HALITE
POTASH
Zechstein 4 = Aller - Series
5-25m
Zechsteinletten
Grenzanhydrit
80-100m
Tonbanksalz
Tonbrockensalz
Rosensalz
Schneesalz
Basissalz
1m
Pegmatitanhydrit
15-35m
Roter Salzton
Zechstein 3 = Leine - Series
Riedel - Group
15m
Grenzsalz
Tonmittelsalz
3-5m
Kalifloz Riedel
35m
Schwadensalz
35m
Anhydritmittelzone
Ronnenberg - Group
75m
Buntes Salz
Bandersalz
Banksalz
6-10m
Kalifloz Ronnenberg
40m
Orangeaugensalz
Liniensalz
Basissalz
0·1-0·2m
Anhydritschale
0·01-0·02-0·1m
Schwarze Tonlage
10-30 30-60m
Plattendolomit
Hauptanhydrit
5-35m
Grauer Salzton
Zechstein 2 = Stassfurt - Series
2-10-35m
Gebänderter Deckanhydrit
0·1-0·5m
Decksteinsalz
10-20-40m
Kalifloz Stassfurt
20m
Kieseritische Ubergangsschichten
400-600m
Hangendsalz
Stassfurt-Steinsalz
Hauptsalz
Basissalz
1-30-100m
Basalanhydrit
5-20-60m
Stinkschiefer
Stinkdolomit
Hauptdolomit
1-10m
Braunroter Salzton
Zechstein 1 = Werra - Series
20-100m
Oberer Werra-Anhydrit
180-240m
60-80m
Oberes Werra-Steinsalz
2-3m
Kalifloz Hessen
60-80m
Mittl. Werra-Steinsalz
2-3m
Kalifloz Thuringen
60-80m
Unteres Werra-Steinsalz
5 30-100m
Unt. Werra-Anhydrit
3-12m
Zechsteinkalk
0·2 0·3m
Kupferschiefer
1-2m
Zechsteinkonglomerat

	Series	Groups	Formations	Cycles
PERMIAN OR TRIASSIC		Eskdale Group	Saliferous Marl	
PERMIAN	UPPER		Top Anhydrite	EZ5
			Sleights Siltstone	
		Staintondale Group	Upper Halite	EZ4
			Upper Anhydrite	
			Upgang Formation	
			Carnallitic Marl	
		Teesside Group	Boulby Halite	EZ3
			Billingham Main Anhydrite	
			Upper Magnesian Limestone	
		Aislaby Group	Fordon Evaporites	EZ2
			Kirkham Abbey Formation	
		Don Group	Hayton Anhydrite	EZ1
			Lower Magnesian Limestone	
			Marl Slate	
	LOWER		Yellow Sands & Basal Breccias	

the Staintondale Group (EZ4) ranges in thickness from 30-70 m. The Zechstein evaporite sequences at Boulby are essentially free of $MgSO_4$ and anhydrite predominates over dolomite.

The Upper Halite is in turn overlain by 100-130 m of Upper Permian and Lower Bunter siltstones, approximately 300 m of brine-saturated Bunter Sandstone, 270 m of Keuper Marl, 20 m of Rhaetic siltstone and mudstone and about 300 m of Liassic clays and siltstones. This sequence appears to be complete apart from two minor disconformities in the upper parts of the Bunter Sandstone and the Upper Lias.

Only the Boulby Halite, Boulby Potash, Boulby Shale and very occasionally, the Carnallitic Marl, are normally exposed in the mine workings away from the shafts.

Upper Anhydrite

This unit is only known at Boulby from the shaft sinking and exploration boreholes. It is a well bedded, very fine-grained, pale grey bed of anhydrite of variable thickness. It is commonly about 10 m thick of which the lowest 0.5-1 m tends to a laminated dolomitic shale. In the shafts, the whole of the Upper Anhydrite undulated with dips of up to 15° and the deformation was seen to have been plastic. Underground upward-looking seismic refraction profiles suggest that such undulations are general and may involve steep fault displacements in some places.

Carnallitic Marl (or Rotten Marl)

This is a stratigraphic term for an anhydrous salt clay which is reddish brown due to the presence of limonite or haematite. It does not contain carbonates in the Boulby area where it is very low in both carnallite and organic content. Porphyroblasts, veins or pods of halite or sylvinite may form up t0 60% of the volume of this brown salt clay locally. No cement binds the clay minerals and the brown salt clay is not self supporting at the depth of the workings. Exposures of this rock in the mine are therefore deliberately rare and rapidly hidden by supports; such temporary exposures provide the upper limit to the geology actually exposed in the mine. Furthermore, upward driling from the workings is usually terminated as soon as the brown salt clay is reached because to drill further requires special techniques in this relatively soft material.

Boulby Shale

This is an informal term referring to a semi-brittle grey shale which forms a zone commonly 1-5 m thick between the brown salt clay and the Boulby Potash. The shale is variable in composition but generally contains chlorite-smectite mixed layer clays (e.g. 30%), illite (10-30%) and anhydrite with minor amounts of talc, magnesite and detrital quartz grains; pyrite is also often present. Veins and porphyroblasts of sylvite locally form such a high proportion of the Boulby Shale that it may often be mined as an ore of potash.

Boulby Potash

This, the principle ore of the potash forming the complex seam at Boulby, is characteristically a gneissose sylvinite, containing approximately equal proportions of sylvite (KCl) and halite (NaCl) with various proportions (e.g. 30%) of relatively insoluble materials, mainly clays and anhydrite. The fabric of the sylvinite is isotropic and granular in a few localities but, far more generally, is gneissose. In exposures larger than a few square metres, the sylvinite of the Boulby Potash has the generally appearance of a migmatised orthogneiss. This visual effect is due to the ubiquitous presence of gneissose bands which range in thickness from millimetres to metres and probably average about 20 cm. Each band has a characteristic grain size (1-10 mm) and colours (grey, pink, orange or red). The migmatitic effect is further enhanced by "xenolithic" inclusions of grey shale (and, more rarely, marl, anhydrite or halite) which occur as isolated inclusions, in trains or in swarms (Figure 4-29).

Boulby Halite

About ±50 m thick, this bedded unit consists largely of massive halite which ranges in colour from white or grey through pink to orange. The colours appear to record a simple stratigraphy with some lateral variation in subordinate mineral assemblages. Infilled solution cavities are recognizable in places.

Deposits of sylvinite are encountered at two levels, at approximately 1067 m and 1524 m and there is irregular occurrence of polyhalite at even greater depths. It is the upper sylvinite bed, overlain by halite, which is of interest in the present case. The bed being exploited, which lies at a depth of 1097 m is 6 m thick and contains sylvinite with an average content of 27% K_2O, i.e. containing 40-45% sylvite (KCl), 45-50% halite (NaCl) and 5-10% other salts, including anhydrite and carnallite, plus insoluble matter. Above the marl, between 610 m and 945 m, is the Bunter Sandstone, an aquifer containing brine at pressures of up to 460 kg/cm^2. The upper 610 m consists of shales, siltstones and mudstones of the Lias and Keuper series overlain by 38 m of boulder clay.

The potash horizon is variable and is classified into three types. These are primary ore where the deposit is uniform, has a mottled texture and contains less than 12% of insoluble material. Dirty secondary ore is where there is +12% of insolubles and the deposit though basically mottled brown contains thin lenticles of shale. Finally, clean secondary ore, which generally lies above a very thin primary

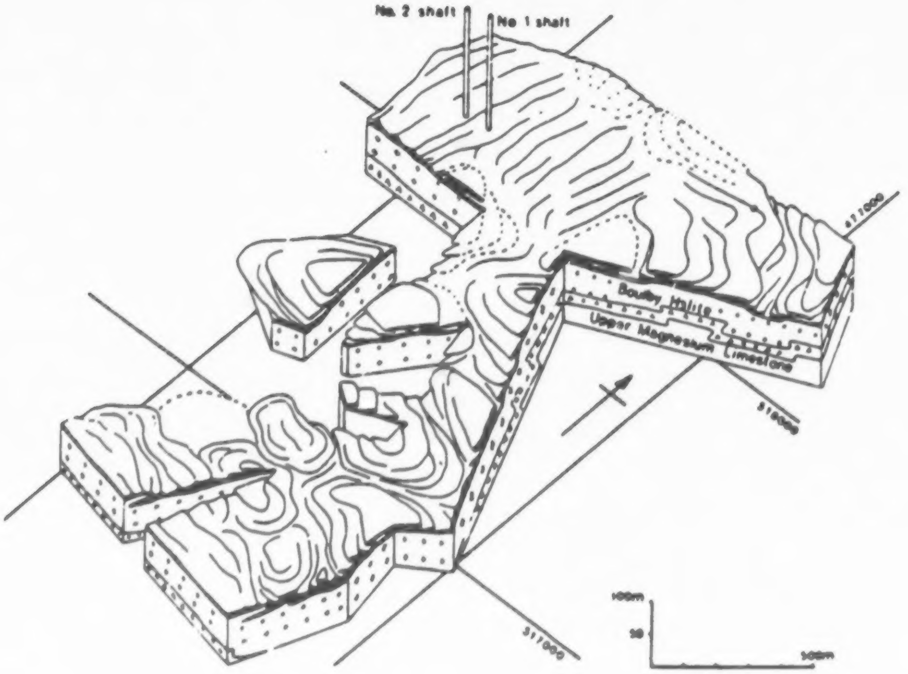

No. 2 shaft
No 1 shaft
477000
Boulby Halite
Upper Magnesium Limestone
516000
517000
100m
50
500m

FIGURE 4-29 DIAGRAM SHOWING EXTREMELY VARIABLE NATURE OF TOP OF POTASH SEAM

deposit, tends to be pink in colour, has obvious geological deformity and has a variable inclusion of shale.

Marl is best described as being a dark brown, compressed mud with practically no strength. At Boulby, it is essential to maintain 1.5 m of ore in the roof below the marl. A breakthrough into the marl inevitably results in a large, uncontrollable fall which is exceedingly difficult to recover. The preservation of such cover sounds simple enough and so it would be if a regular, tabular deposit was being worked. Reference to Figure 4-30 shows a typical cross-section of the seam. Rapid changes in the marl horizon force equally rapid changes in roadway elevations. If a roadway has to dip into salt, this causes undesirable dilution. In addition, adjacent roadways may have to dip in sympathy in order to ensure reasonable gradients at cross-cut holing points which are, of course, shuttle car tramming routes.

In order to monitor the marl horizon exploration holes are maintained ahead of all working faces and geologists are employed on all shifts to ensure rapid interpretation of information which is obtained with the assistance of a gammatrol instrument. It should be noted too that it is very difficult indeed to drill through the marl, because of its muddy nature, and this seriously hampers strata control investigations.

The base of the Bunter sandstone lies approximately 200 metres above the potash seam. It is known, however, from the shaft sinking, that the Bunter mudstones, which lie between the sandstones and the evaporites, contain fissures. This results in a false surface approximatley 80 metres above the workings which requires protection, otherwise flooding or at least serious inconvenience to the mine may occur. Fortunately, the salt beds which lie between the workings and the potentially water-bearing horizon are plastic in nature and provided that they are allowed to bend rather than crack, they form an impervious seal.

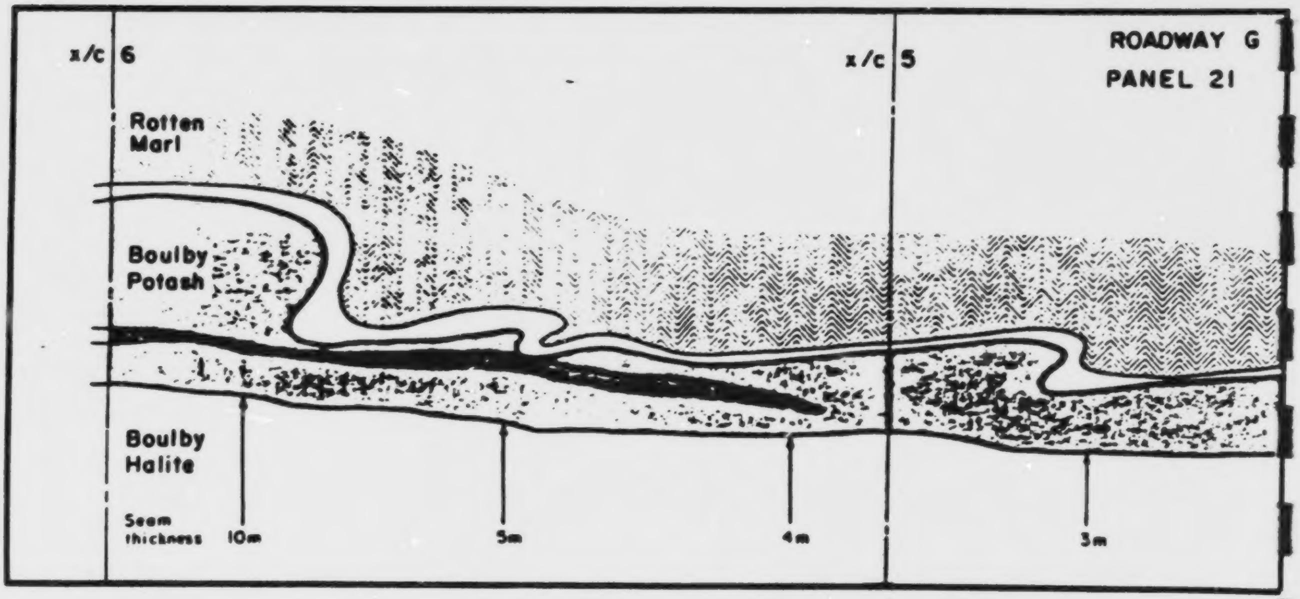

x/c 6
x/c 5
ROADWAY G
PANEL 21
Rotten Marl
Boulby Potash
Boulby Halite
Seam thickness
10m
5m
4m
3m

FIGURE 4-30 TYPICAL SECTION THROUGH SEAM SHOWING VARIATION IN THICKNESS

462 MINING METHODS

Assessment of the initial mining method and equipment was based on:

1. The results of the logs of exploratory boreholes spaced at approximately one mile intervals throughout the projected area of mining.
2. A study of potash mining methods used in other fields throughout the world.

Borehole intersections of the potash seam showed that the mineable thickness of potash would vary from around two metres to 15 metres. The base of the seam appeared to be reasonably level with perhaps dips of up to 1 in 10, whereas the top of the seam fluctuated. Above the potash seam lies a variable thickness of mixed halite and marl rock which appeared to be reasonably competent; the thickness of this bed appeared to vary between zero and two metres. Above this bed lies a bed of red marlstone variable in thickness up to 15 m. This marl was known to be incompetent, hydroscopic and split by potash and halite veins. It is similar to the red marl rock which lies over the salt and anhydrite beds at the nearby Billingham anhydrite mine. Since the red marl bed at Billingham had presented mining problems when it was exposed, it was expected that the same difficulties would be experienced at Boulby. Water-bearing Bunter sandstone formations exist some 70 m above the potash seam throughout the area and it was therefore considered that any method of mining involving caving and collapse of the strata above the potash seam would allow migration of fluid from the Bunter sandstones down into the evaporites and marl and thence into the mine workings, resulting in the formation of cavities by solution. It was therefore decided not to consider any form of mining which would result in caving of the strata, for example, longwall systems.

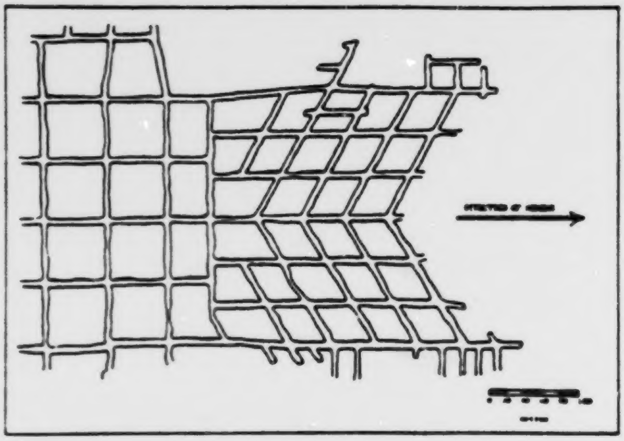
Experimental and theoretical studies suggested that pillars with a width to height ratio of ten would be stable, and creep would not result in failure. It appeared, therefore, that a room and pillar system employing either regularly sized pillars or small pillars protected by larger barrier pillars would be the most feasible method. This was confirmed by visits to potash mines overseas where in almost every case it was normal to employ some form of room and pillar mining.

The use of continuous miners was considered but due to the expected presence of anhydrite in the potash seams, excessive convergence, undulations in floor and roof, and poor roof conditions, it was decided that conventional drilling, blasting and loading would be used to mine the ore.

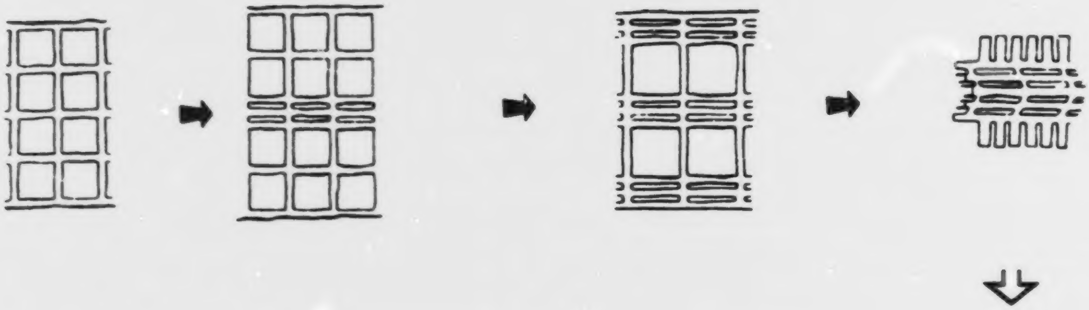
Underground mining operations were started employing conventional room and pillar techniques (6-metre rooms on approximately 36-metre centres, forming approximately 30-metre square pillars). The seam was undercut to a depth of three metres with Joy 15 RU cutter, drilled with Secoma rubber tyred drill rigs, blasted, loaded out with diesel powered Eimco 915 load-haul-dump units onto belts, via Stammler feeder breakers and the roof bolted with Secoma machines.

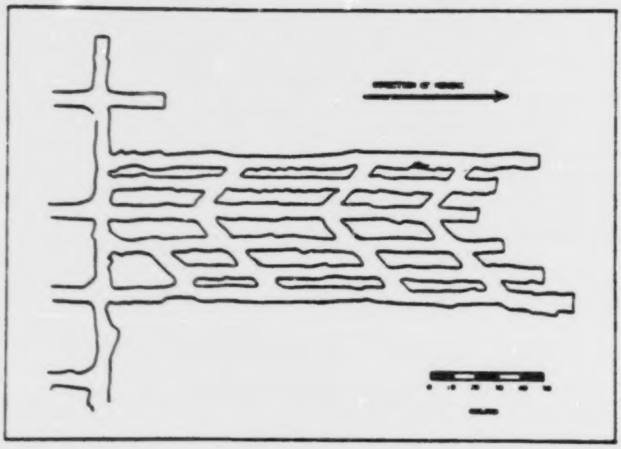
This early system failed because the roadways would not stand up (repair work being necessary within 60 days of mining), extraction was too low (25%) and haulage distances for the LHD too long.

Changes were made using one metre deep slots in the roof as stress relief, but these could not be maintained. Main panel roads were driven with four metre wide pillars between them, but this did not solve the problem. This was followed by a group of three roadways (with four metre pillars) separated by 40 m pillars. The final system uses a 90 metre wide panel with parallel roads separated by narrow pillars and with stub entries round the panel periphery (Figure 4-31). The narrow



PLAN OF A LOW EXTRACTION PANEL WITH ROOM AND PILLAR WORKINGS.





PLAN OF A HIGH EXTRACTION PANEL WITH NARROW YIELD PILLARS.

FIGURE 4-31 EVOLUTION OF ROOM & PILLAR MINING SYSTEM

pillars allow the roof to settle without lateral pressure and hence good conditions are maintained although convergence of up to 700 mm over 400 days occurs.

Further refinements have now limited the panel width to 66 metres giving six working places, and lengthening the cutter jib to give a four metre advance per round. These together with the introduction of a five day working week and a scheduled maintenance shift has resulted in average outputs over 2000 tpd per panel peaking at 3000 tpd.

This system of stress relief mining was fully adopted in 1980.

Mining is organised into five production panels, four of which are in operation at any one time, as one is shut down in rotation to enable necessary maintenance work to be carried out. Each working panel produces 2000 to 2700 t/d ore, and advances by some 20 to 22 m per week. The life expectancy of each panel is about nine months.

The immediate roof is supported by 1.5 m long roof bolts installed on a 1.4 m x 1.4 m pattern employing an Eimco 71 roof bolter which, also installs mechanical side bolts. The bolts are secured with resin which after about one minute, can withstand a seven tonne pull.

The ore is normally cut, drilled and then blasted. The 15 RU Joy Cutter makes a 3.9 metre undercut in the face about one metre above the floor. Under normal conditions, the cutting process takes approximately 45 minutes.

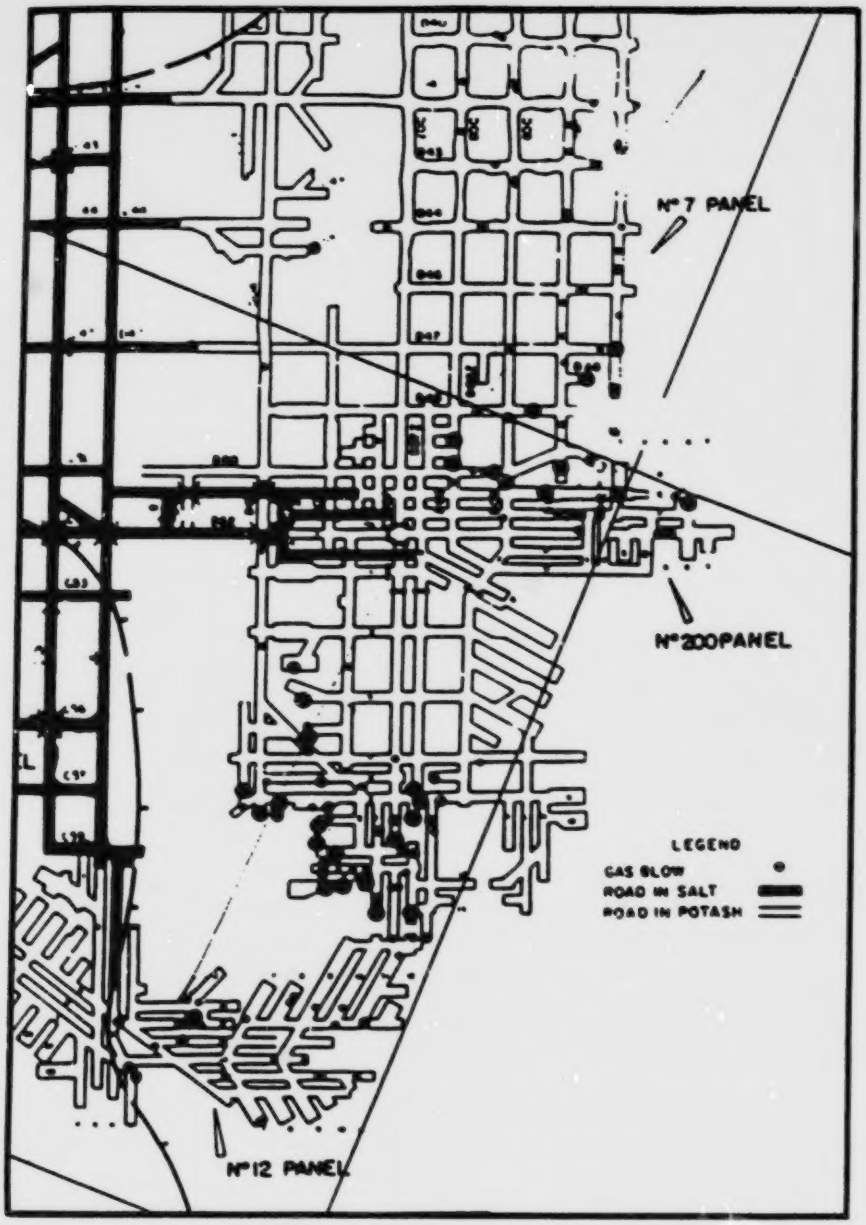
After cutting the ore, a series of holes (three rows of seven holes above the undercut, and one row of nine holes under the cut), 3.75 m in depth and 43 mms in diameter, are drilled into the rock face using an Eimco 711 Long Boom Drill. This latter piece of equipment is also used by the panel geologists to drill exploration holes to measure with a probe the gamma ray emitted from the rock and thus determine the amount of KCl present in the rock up to 26 m ahead.

Following drilling, the panel face is blasted using a nitroglycerine-based explosive. The average amount of ore released in each round is 180 tonnes. A Heliminer H.R. 120 continuous miner trims the roadway and then loads the ore at a rate of 150 t/h and dumps it into eight tonne cablereel shuttle cars, for transport via the conveyor belt system to two vertical bunkers each of 1000 tonnes capacity.

The potash seam at Boulby contains gas and is subject to gas blows. The continuous miners are therefore only used to cut and mine the ore in areas where gas blows are unlikely to be encountered (mainly in the primary ore where shale inclusions are absent). In areas liable to gas outbursts, drill and blast methods are used so that any potential gas blow is triggered by blasting (Fig. 4-32).

The mine is also experimenting with a large diameter (400 mm) auger drill. By drilling two such holes to act as the cut on a working face, it is hoped to reduce the total number of blast holes drilled per face, increase the length of the round broken, reduce explosives consumption, and lessen the exposure of the Jeffrey Heliminers to possible gas blows whilst face cleaning.

The workings at Boulby have become somewhat extended, and in order to improve productivity and travelling conditions, twin drivages in the salt beneath the potash workings have been driven to both the northeast and the western working areas. These provide shorter routes between these areas and the shafts. They are equipped with a conveyor permitting two way manriding as well as one transport. This has reduced transport times for workers. The mine is now producing up to 8000 tpd.



Nº7 PANEL
Nº200PANEL
Nº12 PANEL
LEGEND
GAS BLOW ●
ROAD IN SALT
ROAD IN POTASH

FIGURE 4-32 INCIDENCE OF GAS-BLOWS IN PANELS 7 & 12

The mining operations at Boubly are a demonstration that potash can be successfully mined at depth in spite of the hazards of heat, gas, rock pressure and aquifers.

463 GEOTECHNICAL ASPECTS

Potash mining in UK utilizes a room and pillar mining system at a depth of approximately 1140 m below surface. Mining operations started in 1974 with six metre wide rooms and 30 m square pillars, and major problems were experienced in maintaining roof and pillar wall stability. Because of this, development roadways were located in the footwall salt.

The deposit is flat lying, although the geology is complex and the mining seam is quite erratic in nature. The potash is overlain by marl, a dark brown anhydrous salt clay. This marl is extremely weak and it is necessary to maintain 1.5 m of ore in the roof below the marl to prevent large uncontrollable roof falls. Because of the irregular nature of the orebody, the marl horizon undergoes rapid changes and roadway elevations need to follow these changes. Monitoring of the marl horizon is difficult because of problems associated with drilling into the weak marl.

A major aquifer, the Bunter sandstone lies approximately 200 m above the potash seam. This is underlain by a fractured mudstone, the base of which is 80 m above the workings, and then a salt bed, the thickness of which is poorly known. The salt bed forms an impermeable barrier between the overlying water bearing formations and the workings.

It is reported that the roof in the six metre wide rooms of the initial layout were supported by rockbolts and steel straps but roof failures still occurred due to lateral stress caused by horizontal movement of the pillar walls. Slots 170 mm wide by one metre deep were cut longitudinally down the centre of the roadway to relieve the lateral stress, but this did not prove to be a practical relief method. The excavation of multiple entry roadways proved to be more successful, particularly with four to five parallel roads with narrow yield pillars in a 66 to 90 m wide panel and with multiple stub entries perpendicular to the two outside roadways. Long term convergence in the roadways ranges between approximately 450 and 650 mm per year.

4.7 FRANCE

471 GEOLOGICAL ASPECTS

Potash deposits of the Rhine Valley are the result of marine ingression into the Oberrhein Graben during the Eocene period. The rift zone has a length of about 300 km and a width of 40 km within which three subbasins bearing potash salts have been isolated by flexures induced during late Alpine orogeny:

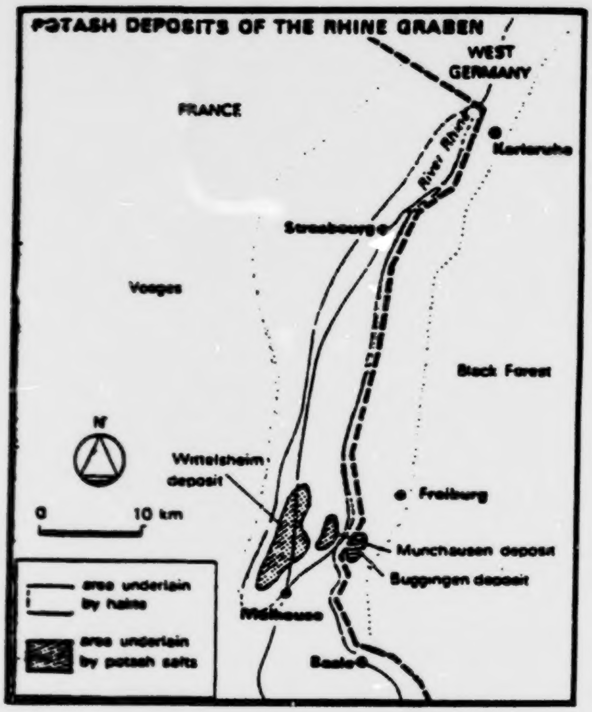
1. The deepest and largest Wittelshein subbasin (France).
2. The Münchhausen or Grissheim subbasin (France).
3. The Buggingen subbasin (West Germany).

Six evaporitic cycles occur within an 80 to 100 m thickness of the Upper Eocene - Lower Oligocene Pechelbronn beds. (See Table 4-4). A normal cycle includes basal anhydritic marl, an overlying halite bed, and, in cycles 2 and 3, a potash zone at the top.

The cycle 3 or upper potash bed is developed exclusively in the western Alsace or Willelshein subbasin where the upper and lower zones are separated by up to 20 m of halite and marl.

The active mining area at present is in the Wittelsheim deposit where three mines are now in production. Mines de Potasse d'Alsace operates the Amelie, Marie-Louise, and Theodore mines at depths between 420 and 1100 m (Fig. 4-33).

The upper potash bed varies between 1.2 and 2.1 m in thickness and may contain 22 to 25 percent K_2O. The lower bed is comprised of five potash laminae separated by clays or halite and varies between 2.4 and 5.0 m thick. Grades range between 14 to 20 percent K_2O. The


POTASH DEPOSITS OF THE RHINE GRABEN
WEST GERMANY
FRANCE
Karlsruhe
River Rhine
Strasbourg
Vosges
Black Forest
N
Wittelsheim deposit
0
10 km
Freiburg
Munchausen deposit
Buggingen deposit
area underlain by halite
area underlain by potash salts
Mulhouse
Basle

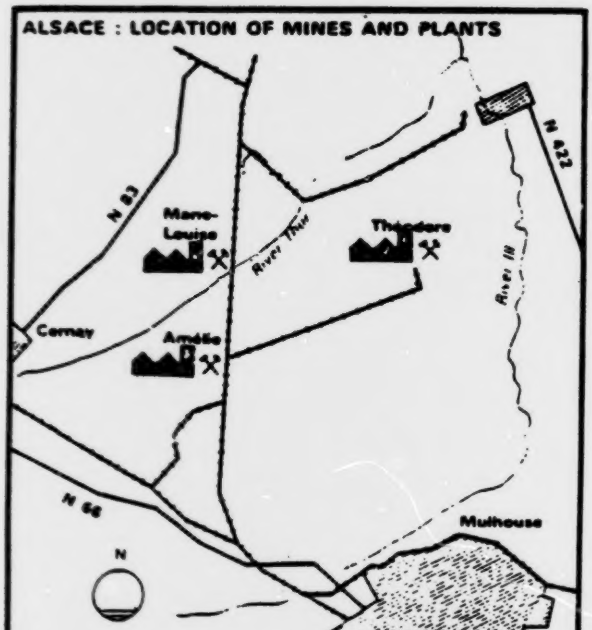

ALSACE : LOCATION OF MINES AND PLANTS
N 422
N 83
Marie-Louise
River Thur
Théodore
River Ill
Cernay
Amélie
N 66
Mulhouse
N
0
5 km

FIGURE 4-33 LOCATION OF POTASH BASINS
AND MINES - FRANCE

TABLE 4-4

Sequence of Pechelbronn-Beds

(acc. to GUNZERT)

Bunte	400 m	+ gypsum + anhydrite	60-80 m
Mergel		gray and red marls with nodules of anydrite and beds of halite	300 - 350 m
Obere Bituminose Zone	80-100 m	halite anhydr. marl	VI. cycle
		halite anhydr. marl	V. cycle
		halite anhydr. marl	IV. cycle
		Upper K bed halite anhydr. marl	III. cycle
		Lower K-bed halite anydr. marl	II. cycle
		halite anhydr. marl	I. cycle
Fossilreiche Zone	80-80 m	dark carbonatic marls	

two beds are separated by approximately 21 m of halite and anhydrous marl (Fig. 4-34).

Beds in the southern portion of the Wittlesheim deposit dip eastwards 0° to 35°. A series of north-south oriented faults intersect the subbasin.

472 MINING ASPECTS

Potash was discovered in France in 1904. Development commenced in 1908 and Amelie mine began production in 1910. Eventually 12 mines produced potash in the Alsace deposit. As stated previously only three mines are operating at the present time.

The original mining method was room and pillar by means of undercutting, blasting and hand-loading. The first shearer-type longwall mining system was introduced in France in 1948. In 1981 the room and pillar mining method was abandoned and all mining, except development headings, is now performed by longwall equipment with total caving.

The longwall mining method employs shearers with fixed cutting drums. These machines are used to work two seams concurrently, with the upper seam being mined 25-30 m ahead of the lower seam. The worked-out section of the upper seam is allowed to cave and in turn is followed by the second. Both faces are worked simultaneously on the retreat. The mining faces are supported by self-advancing support systems with four leg-chocks advanced every 3-5 m behind the shearer.

The following illustrates the method of mining at the Amelie mine. This is located in Section 75 (see Figure 4-35) and gives a good

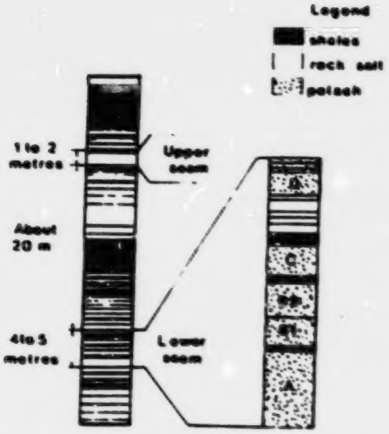

Legend
shales
rock salt
potash
1 to 2 metres
Upper seam
About 20 m
4 to 5 metres
Lower seam
D
C
B2
B1
A

FIGURE 4-34 SECTION THROUGH DEPOSIT NEAR THE POTASSIUM BEARING ORE BODY (I) AND SCHEMATIC SECTION OF THE LOWER SEAM FOR WHICH THE HEIGHT CAN REACH 5m THICKNESS (r)

example of the state of mechanization in a relatively flat area (2°-4°). There are three retreating faces using shearers, each face having a length of 250 m (see Figure 4-36).

The longwall machine has two drums each driven through a 400 kW motor/gear assembly. The two drums are respectively 2.0 and 1.8 metres in diameter and 1.1 metre web. The heights that are cut are 3.25 and 3.45 m corresponding to the working height from B and A to C^1 (see Figure 4-37).

The unidirectional cutters, designed by MDPA, are equipped with a 50 t winch which hauls the cutter on the floor between the conveyor and face allowing a practical cutting depth of 1.05 m at a speed of 96 m/h. The output rate is 700 t/h. Remote control allows the operator to move about independent of the machines.

The potash ore is removed by a chain conveyor powered by a 400 kW motor and chain velocity is 1.3 m/s.

The roof supports placed at 2.5 m along the face are hydraulic chocks with four 120 t legs. The supports include a forward canopy with two extended arms which are advanced into the cut and set hydraulically behind the shearers which support the newly exposed roof. A rear shield, suspended from the back of the canopy prevents the caved material from flushing into the chocks.

Each face employs its own transportation system which discharges the potash ore into a bunker, thus providing some independence from the main haulage system.

A telescopic transfer chain conveyor in each roadway feeds through a crusher to ensure that the ore is suitable for the 1200 mm width conveyor belt.

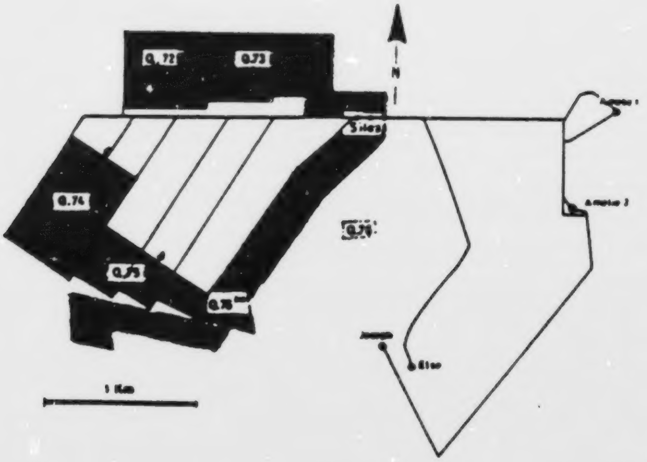

Q.72
Q.73
N
Q.74
Q.75
1 Km

FIGURE 4-35 LONGWALL MINING IN FRANCE - AMELIE MINE
PLAN OF DISTRICT Q.75 (3 LONGWALL FACES)

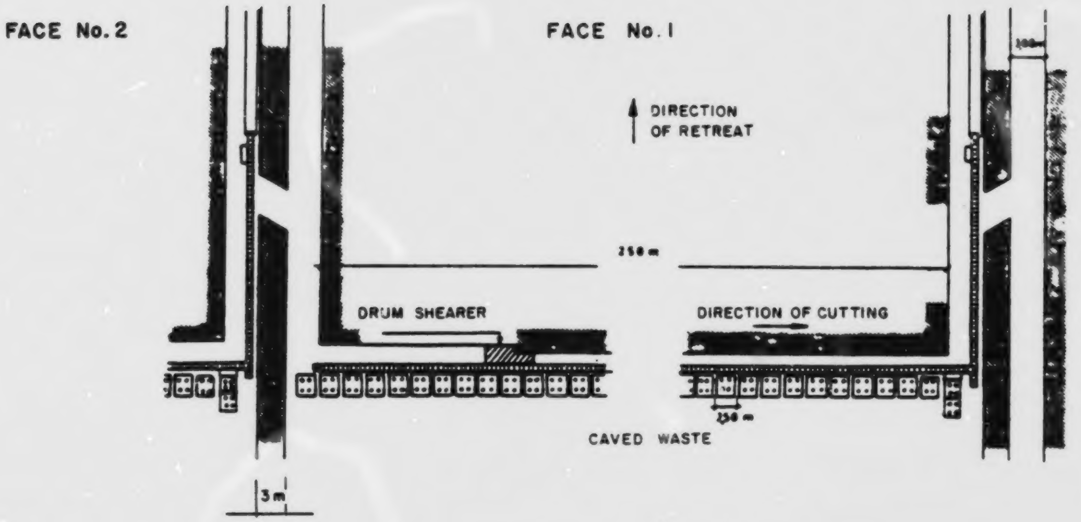

FACE No.2
FACE No.1
100m
DIRECTION OF RETREAT
250 m
DRUM SHEARER
DIRECTION OF CUTTING
250 m
CAVED WASTE
3 m

FIGURE 4-36 LONGWALL MINING IN FRANCE - AMELIE MINE
LAYOUT OF ONE LONGWALL FACE

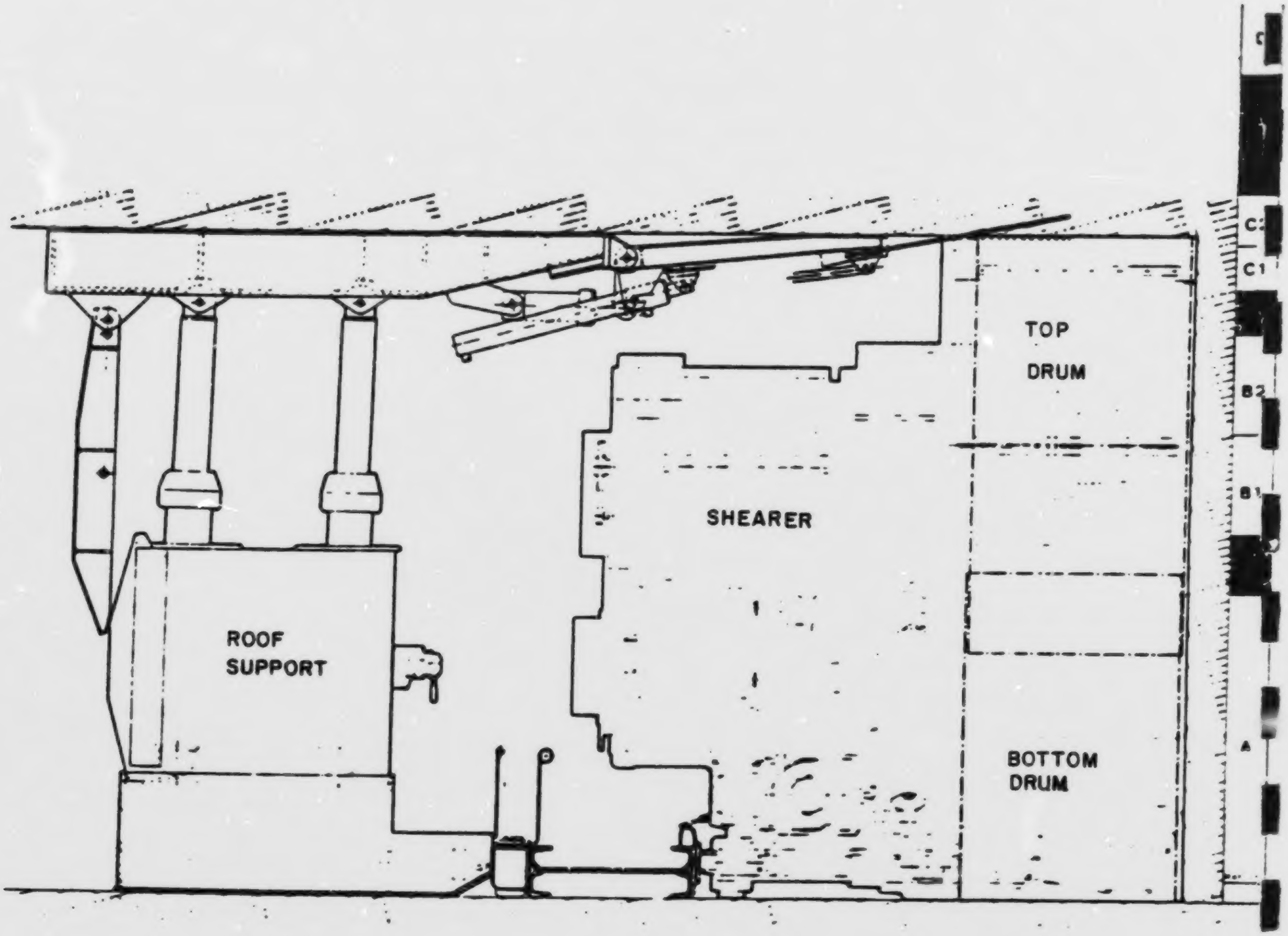

TOP
DRUM
SHEARER
ROOF
SUPPORT
BOTTOM
DRUM
C2
C1
B2
B1
A

FIGURE 4-37 SECTION THROUGH LONGWALL FACE INCLUDING POTASH BEDS

Each mining face has its own ventilation system; thus, allowing heat and dust to meet the required standards and to limit the effects of gas emissions and outbursts.

A remote sampling methanometer samples various centres such as electrical stations, auxiliary ventilation and return airways at frequent intervals. This information is transmitted directly to surface.

Final clean-up of the face ends is provided by two small scoop trams.

Two faces of the section work three shifts per day while the third face works four shifts per day. The men changeover at the face to permit continuous operation of the machines. The three shifts per day represent 16.5 producing hours, while the four shift system gives 20.6 hrs. The normal manning level per day is 66 production workers, 18 maintenance staff and 20 supervisory staff.

The daily tonnage reaches 11 000 t thus corresponding to approximately 3 700 t per day per face. Average monthly productivity (production and maintenance) has exceeded 100 t per man shift.

Continuous miners are employed to mine development headings. They have the ability to drive headings with cross gradients up to 27°. Two developing heads are driven parallel to each other. The development headings are 3.9 m wide separated by a 3 m wide pillar. Where the salt back is thick the development headings are widened to six metres. Two different miners are used: Paurat E 195 "boom-miner" and the Stephanouse Douaisis Sabes MTP 52 "Tilting-Drum Miner". Shuttle cars and conveyors are used to transport the ore from the face to the shaft.

Studies have been continuing since 1980 to improve the face operations of the panels. The aims of these studies are:

- To improve the shearers' performance at smaller than average height ranges and average height ranges, and to extend the height above 3.5 m. MDPA are targetting for a four metre height.

- To increase the strength and bearing capacity of the supports which is necessitated by the increased cutting height of shearers. Prototype chocks are now in service having six 140 t legs and are destined for 4 m height.

- To improve dust suppression, lighting and communications.

Gross current run-of-mine production from the three mines is 11.3 million tonnes per year which relates to approximately 1.8 million tonnes of K_2O. Production is not expected to increase because of problems in disposing of waste salts.

The three mines have a limited life and present plans envisage that these mines will cease operation by the year 2000.

473 GEOTECHNICAL ASPECTS

Both room and pillar and longwall mining methods have been used in France to mine potash although all production except for potash recovered from development headings is now from longwall method at depths of 420 to 1100 m below surface. Many of the workings dip up to 35° and rock temperatures are generally high, particularly at depth. The significant dip of the orebody was one of the factors in adopting the longwall method.

Pillar mining with one hundred percent extraction in a mining block 800 m wide by over 1400 m long was undertaken in at least one of the mines and it is understood that no major stability problems were experienced, the roof caving readily behind the longwall face in both seams.

4.8 SPAIN

481 GEOLOGICAL ASPECTS

Basinal development leading to accumulations of evaporite strata began at the end of the Late Carboniferous with the Hercynian Orogeny. The western half of the peninsula experienced extensive magmatism and metamorphism whereas the eastern portion of the region started to subside and form a basin which persisted until the Miocene.

Although saline deposits developed as early as the Permian in Spain, those of most economic importance for potash production are confined to the Oligocene strata in the northeastern district of Catalonia near Barcelona and in northern Spain close to Pamplona (Fig. 4-38). A large depression containing these beds was accentuated by orogenic events which uplifted the Pyrenees to the north, the Catalonia ranges to the east, and the Iberian Mountains in the south. A limited access was maintained to the open sea towards the east.

Potash beds in the two subbasins are noted to have similar geological characteristics, differing only in some detail. The eastern subbasin is larger than the western one.

Deformation of the strata has resulted in a series of folds and some anticilinal developments are interpreted to be semidiapiric in character (Fig. 4-39). In the eastern or Catalonian subbasin potash beds near the top of the anticlinal axes are exploited whereas in the western Navarra subbasin potash salts are mined in synclines which have been truncated by erosion. Both occurrences represent shallower mining conditions in these respective areas (Fig. 4-40).

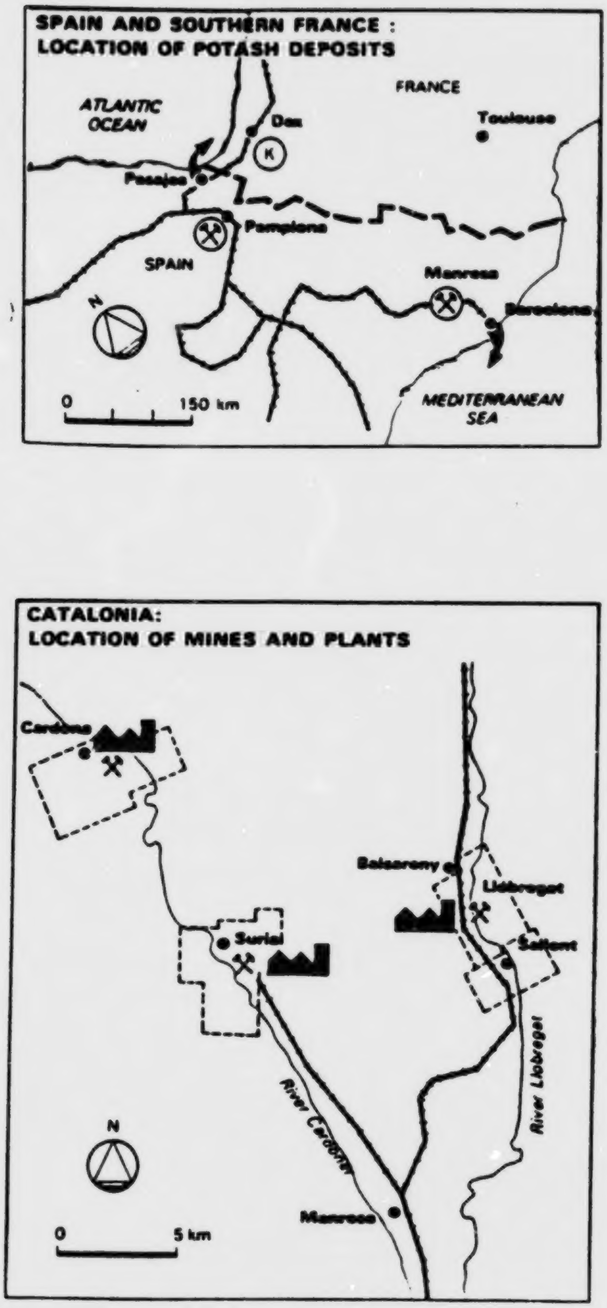

SPAIN AND SOUTHERN FRANCE :
LOCATION OF POTASH DEPOSITS
FRANCE
ATLANTIC OCEAN
Dax
K
Toulouse
Pasajes
Pamplona
SPAIN
Manresa
Barcelona
N
0
150 km
MEDITERRANEAN SEA
CATALONIA:
LOCATION OF MINES AND PLANTS
Cardona
Balsareny
Llobregat
Suria
Sallent
River Cardoner
River Llobregat
N
0
5 km
Manresa

FIGURE 4-38 LOCATION OF POTASH MINES - SPAIN

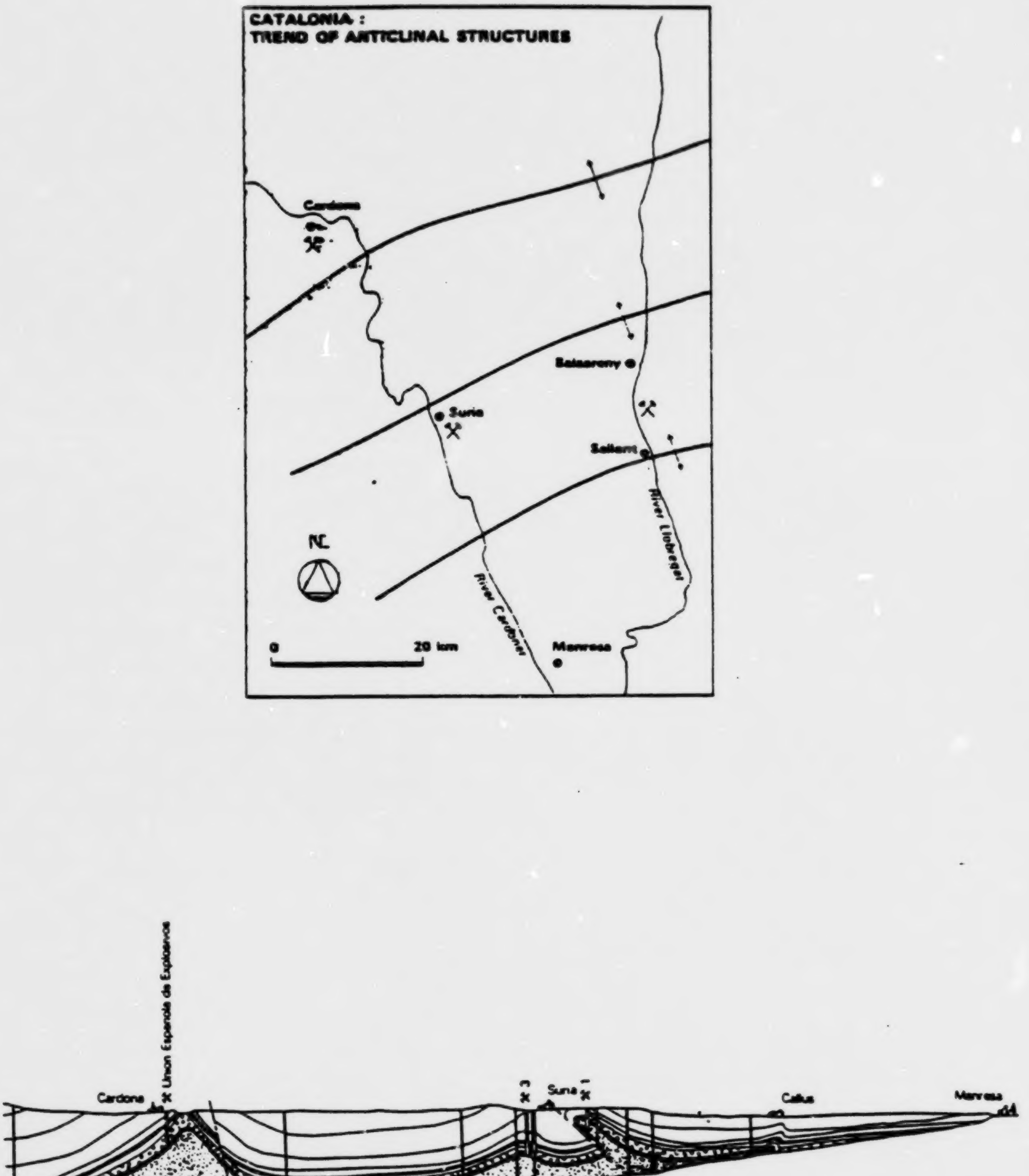

CATALONIA :
TREND OF ANTICLINAL STRUCTURES
Cardona
Balsareny
Suria
Sallent
River Llobregat
River Cardoner
Manresa
N
0
20 km
Union Espanola de Explosivos
Cardona
Suria
Callus
Manresa
Carnallite
Sylvinite
Rocksalt

FIGURE 4-39 SECTION & PLAN SHOWING MAJOR ANTICLINAL STRUCTURES

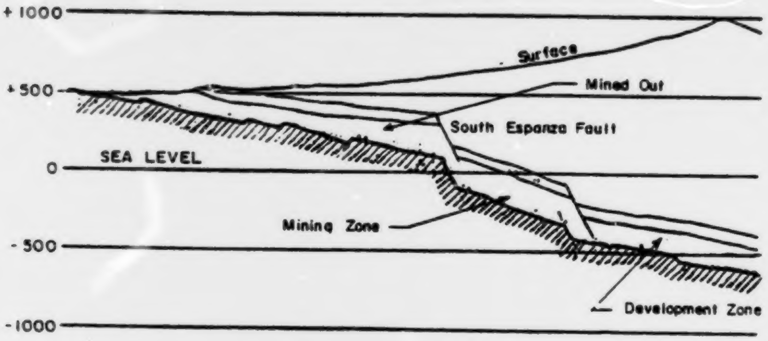

+1000
Surface
+500
Mined Out
South Esparza Fault
SEA LEVEL
0
Mining Zone
-500
Development Zone
-1000

FIGURE 4-40 SECTION THROUGH NAVARRA POTASH FIELD

Sylvite is the most common potash mineral present and may be locally accumulated in folds. Carnallite is also present and forms a variable constitutent of the commercial potash zones. The principal sylvinitic beds are overlain by carnallite in the Catalonia region (Table 4-5).

Fold axes are orientated in an approximate east-west direction in the Catalonia area. Disturbances in the Balsareny (Llobregat-Sallent) mining district are greater than those in the vicinity of the Cardona and Suria mines to the west.

The ore body at Navarra forms part of a syncline structure which is criss-crossed by two systems of faults (NE to SW and NW to SE). Four potential mining zones have been outlined, the zone nearest the surface having been mined out. (Fig. 4-40).

The beds dip consistently but depth below surface is also governed by surface topography and the downthrow faults.

482 MINING METHODS

Potash mining in Spain is carried out in the Provinces of Navarra (the Esperza mine of Potasas de Navarra -PDN) and Barcelona (the Cardona and Llobregat mines of Union Explosivos Rio Tinto (ERT), and the Suria mine of Mines de Potasa de Suria).

In the PDN mines, the longwall method of mining is employed because the conditions are best suited to that method - namely medium thick seams (2 m+) and gently dipping consistent beds.

Conditions in the Barcelona province vary considerably and as a consequence, so do the mining methods. In the deep steeper, thicker

TABLE 4-5

SPANISH POTASH MINES

Mine	Potash Zone	Depth in Metres	Ore Type	Mining thick in metres	K_2O (%)	Insols. %	Reserves
	CATALONIA						
Cardona Union Explosivos Rio Tinto		820	sylvinite	5 - 20	16.5 in sylvinite	-	62.5 Mt
LLobregat Union Explosivos Rio Tinto		400	sylvinite	6 - 8 carn. and halite 0.8 sylvinite 2 halite 3.2 sylvinite	22.5 in sylvinite	-	16.0 Mt
Suria - Minas de Potasa de Suria	B	550 - 680	sylvinite below carn.	2 - 8	19 in sylvinite	-	-
	A	550 - 680	sylvinite				
	NAVARRA						
Pamplona - Potasas de Navarra SA		200 - 1500	carnalite sylvinite	2.5 1 halite 2	12 22	-	-

deposits at Cardona, sub level open stoping is used. At Llobregat where the medium thick deposits are relatively flat, room and pillar with long chevron rooms is applied, whilst in the mixture of flat and steep seams at Suria, room and pillar mining with limited stoping is employed.

Brief descriptions of the mining methods used at Cardonna, Llobregat and Esperza are given below.

Cardona Mine

Cardona is mining a deep lying, diapir fold deposit by highly mechanized sublevel caving method (Figures 4-41 and 4-42).

A fleet of 15 rubber tired jumbos and 18 load-haul-dump units drill and load out the potash salt via feeder breakers to a conveyor system that conveys it to the surface.

In section, the potash seam at Cardona, forms the horse-shoe-shaped periphery of a dome-shaped salt intrusion, the potash horse-shoe being about one kilometre across and about five kilometres long. The potash periphery varies in thickness from eight to 20 metres.

The material mined at Cardona comprises carnallite and rock salt, both of which go to waste, and the ore mineral, sylvinite. The ore contain between 11 and 12 percent K_2O and proven reserves will allow the mine to continue at its present production rate for more than 40 years.

Cardona is served by two shafts and a surface drift.

The main haulage levels are of seven metre by four meter section and are roof bolted when necessary, which is rare. All other development is mined to a five metre wide by 3.5 m high section. In

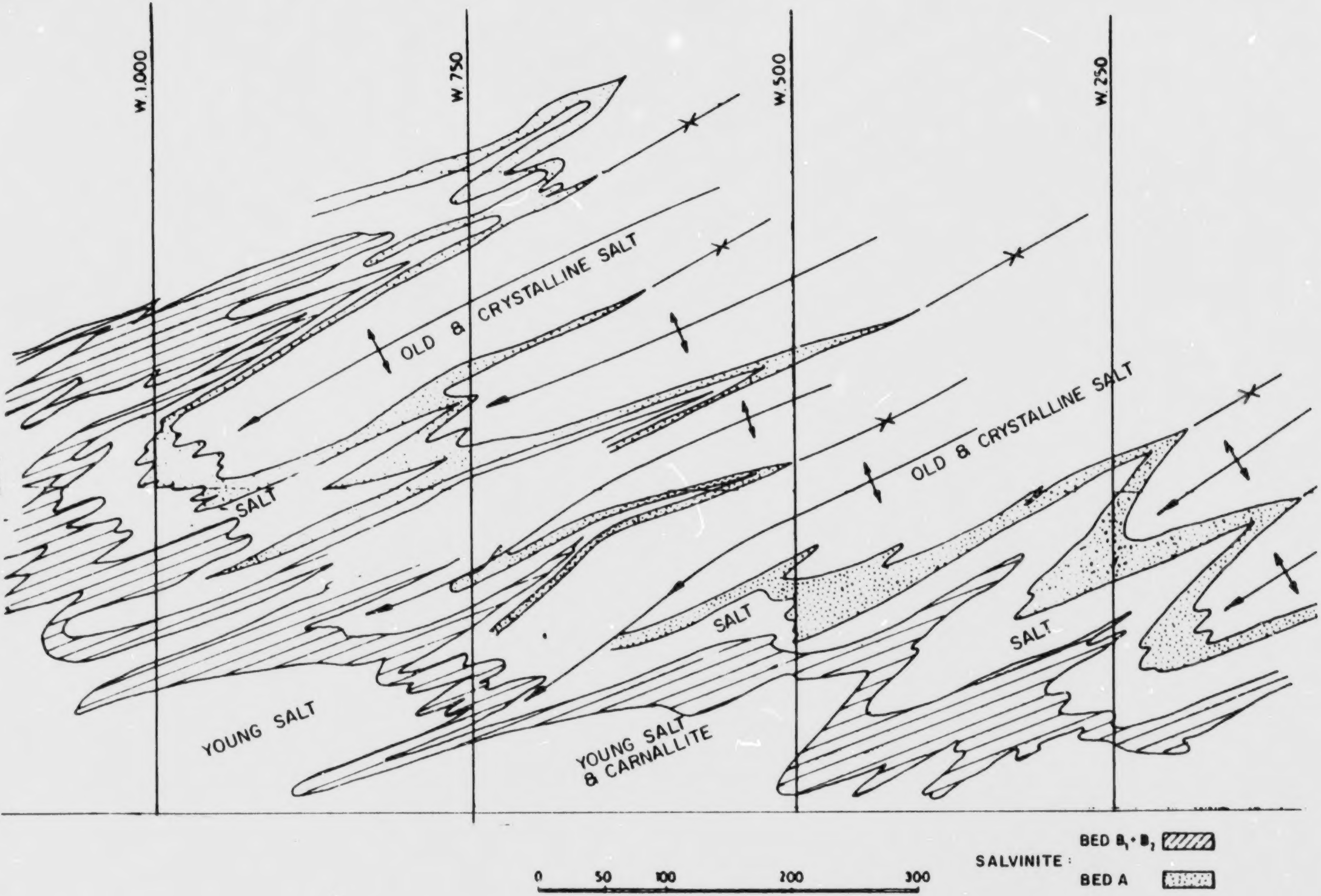

W.1,000
W.750
W.500
W.250
OLD & CRYSTALLINE SALT
OLD & CRYSTALLINE SALT
SALT
SALT
SALT
YOUNG SALT
YOUNG SALT & CARNALLITE
0
50
100
200
300
SALVINITE :
BED B1 + B2 ▨
BED A ▒

FIGURE 4-41 GEOLOGICAL PLAN - 1000m LEVEL

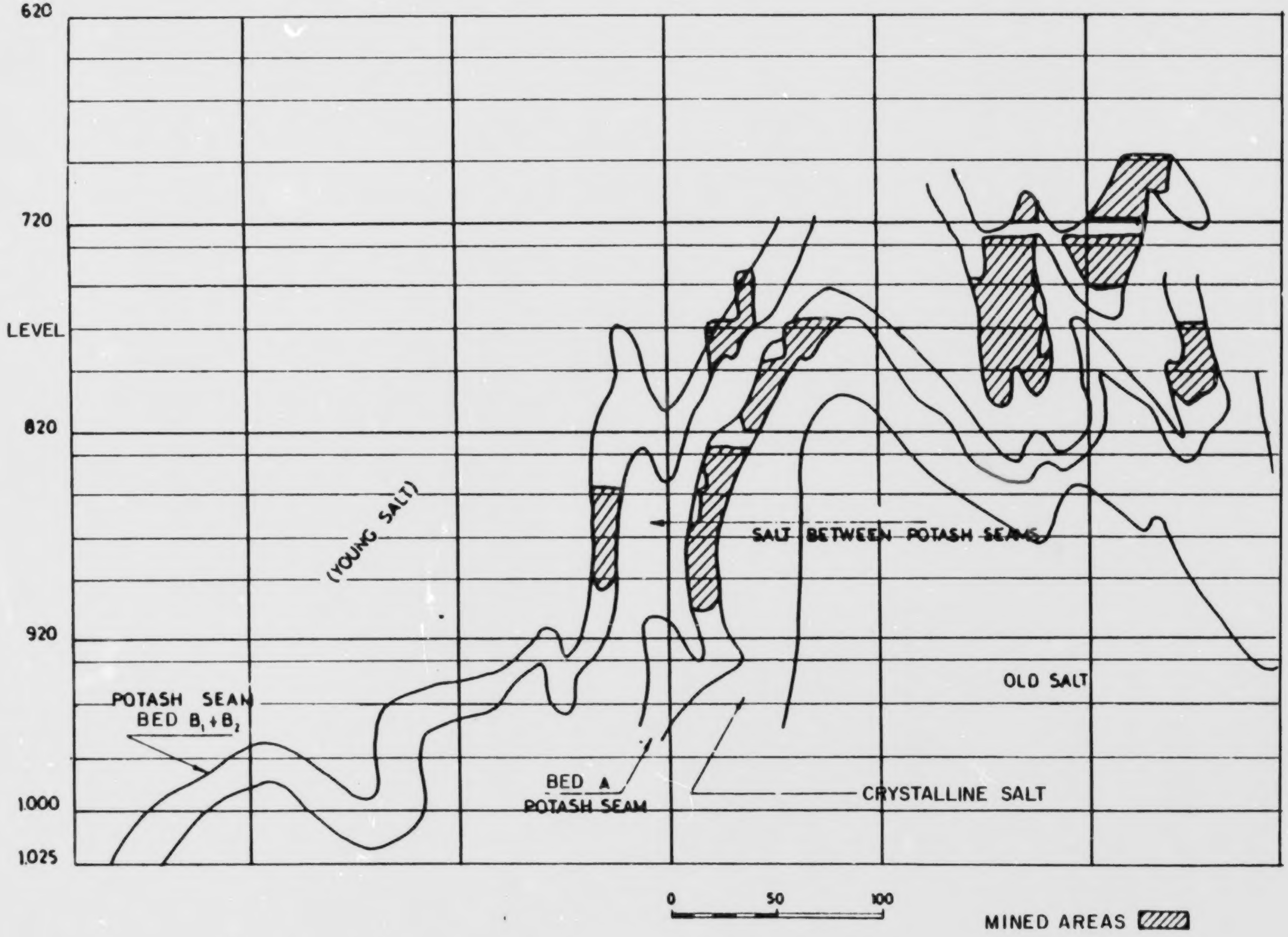

620
720
LEVEL
820
920
1,000
1,025
(YOUNG SALT)
SALT BETWEEN POTASH SEAMS
OLD SALT
POTASH SEAM
BED $B_1 + B_2$
BED A
POTASH SEAM
CRYSTALLINE SALT
0
50
100
MINED AREAS ▨

FIGURE 4-42 GEOLOGICAL SECTION THROUGH MINE WORKINGS

development headings conventional drilling and blasting techniques are used with a burn cut being the drilling pattern. The central hole of the cut is drilled by an auger bit with a diameter of 420 millimetres, the remaining holes being 45 millimetres diameter. All development drilling jumbos drill four metre rounds.

Load haul-dump units carry development ore to feeder breakers which, besides performing primary crushing, are the feed points to the mine's conveyor system.

In the development of main haulages the drilling, blasting, and mucking operations are followed by a trimming and general cleaning up of the roof and walls using a small Westfalia Lunen roadheader. This ensures a clean, smooth profile that increases the effectiveness of the ventilation and reduces accidents from roof spalling.

Sublevel open stoping is employed for ore production. Crosscuts are driven into the ore body at 20 metre vertical intervals and stopes 100 meters high are developed across the width of the potash bed. The present production level is the 920 metre level (production having originally started on the 550 metre level.) with development and production from the 1020 metre level (Figures 4-43 and 4-44).

Following the establishment of the crosscuts, two cones are mined at the base of the stope. These will feed into a loading crosscut off the main haulage. Slots are established between each production crosscut, by drilling upwards from the level below, to provide the initial free face for blasting. Stoping blastholes are drilled downwards between each level and blasting proceeds from the bottom of the stope upwards.

The ore is collected from the drawpoints by LHD units.

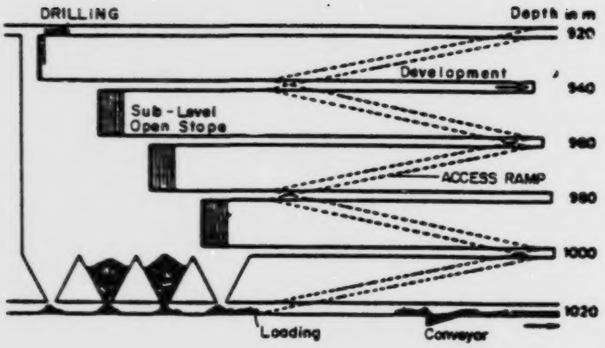

DRILLING
Depth in m
920
Development
940
Sub - Level Open Stope
960
ACCESS RAMP
980
1000
1020
Loading
Conveyor

FIGURE 4-43 TYPICAL OPEN STOPING METHOD

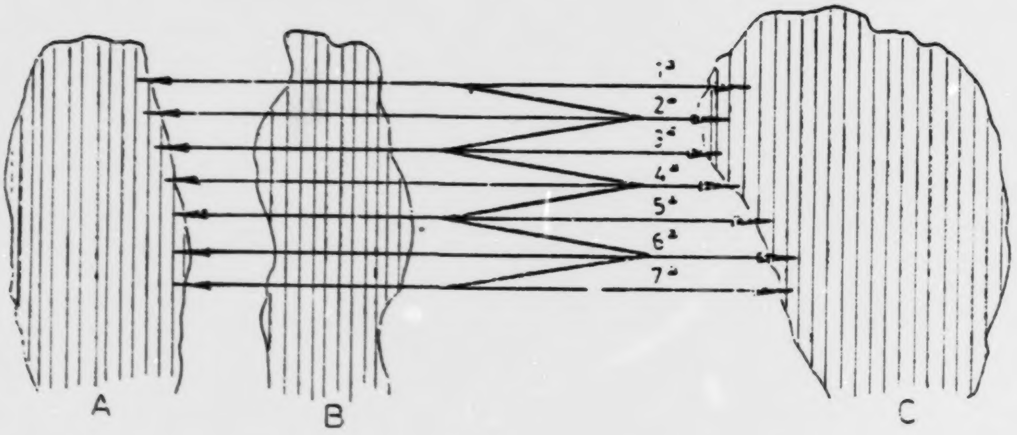

1
2
3
4
5
6
7
A
B
C

FIGURE 4-44 SECTION THROUGH ADJACENT LIMBS OF OREBODY SHOWING SUB-LEVELS AND ACCESS RAMPS

The LHD's carry the ore an average of 200 metres before dumping in to feeder breakers. (Figure 4-45).

From the time that the ore is dumped into the feeder breakers, the further transportation through the mine and up the drift to the processing plant is fully automatic. Conveyors carry the material to a hammer mill, where it is further reduced to a maximum size of 50 millimetres (2 inches). It is then conveyed to one of two 3000-tonne storage bins which were mined in the salt dome. The capacity of these bins provides a buffer against transport capacity fluctuations caused by breakdowns anywhere in the mine, the plant, or in between. The drift forms the final link between the mine and the processing plant.

The ore is transported to surface up the San Onofre drift by conveyor belt. This conveyor system, some four kilometres long, includes a series of eight high horsepower drive heads and is one of the greatest conveyor lifts in the world. From the bottom of the mine to the plant is a vertical height of about 1100 metres.

Llobregat Mine

The potash seams of the Llobregat area have remained relatively undisturbed and dip at an angle of 5° to the northeast. There are two sylvinite beds, the upper one being 0.7 to 0.9 metres thick and much the richer seam, containing an average 35% K_2O. The lower seam is 3.0 to 3.2 metres thick and contains an average 18% K_2O.

The two seams are separated by a salt band about two metres thick. This approximately six metre thick strata is overlain by seven to eight metres of carnallite and halite, with a very thick rock salt bed below the sylvinite beds (Fig. 4-46).

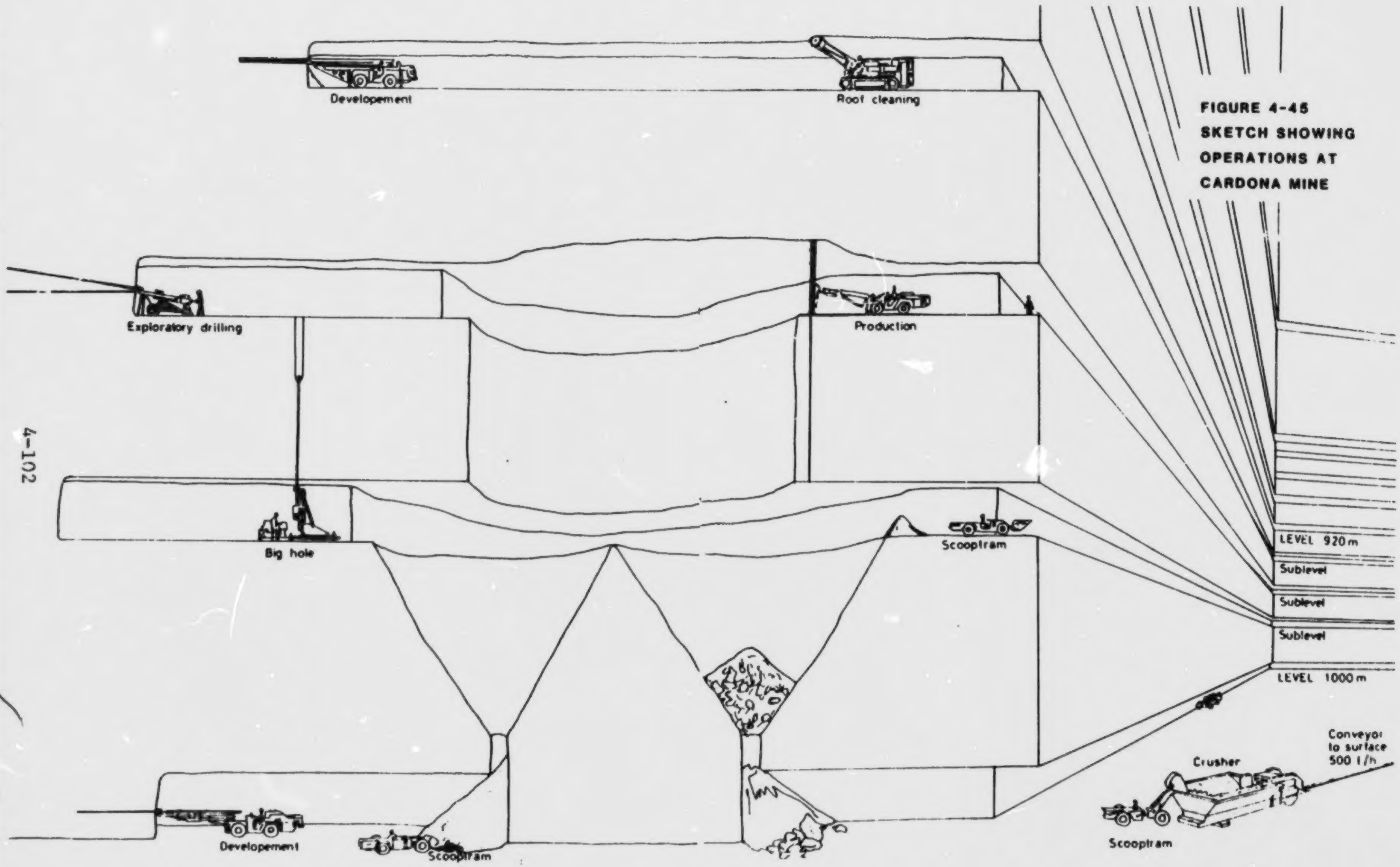

Developement
Roof cleaning
Exploratory drilling
Production
Big hole
Scooptram
LEVEL 920 m
Sublevel
Sublevel
Sublevel
LEVEL 1000 m
Conveyor to surface 500 t/h
Crusher
Scooptram
Developement
Scooptram

FIGURE 4-45
SKETCH SHOWING
OPERATIONS AT
CARDONA MINE

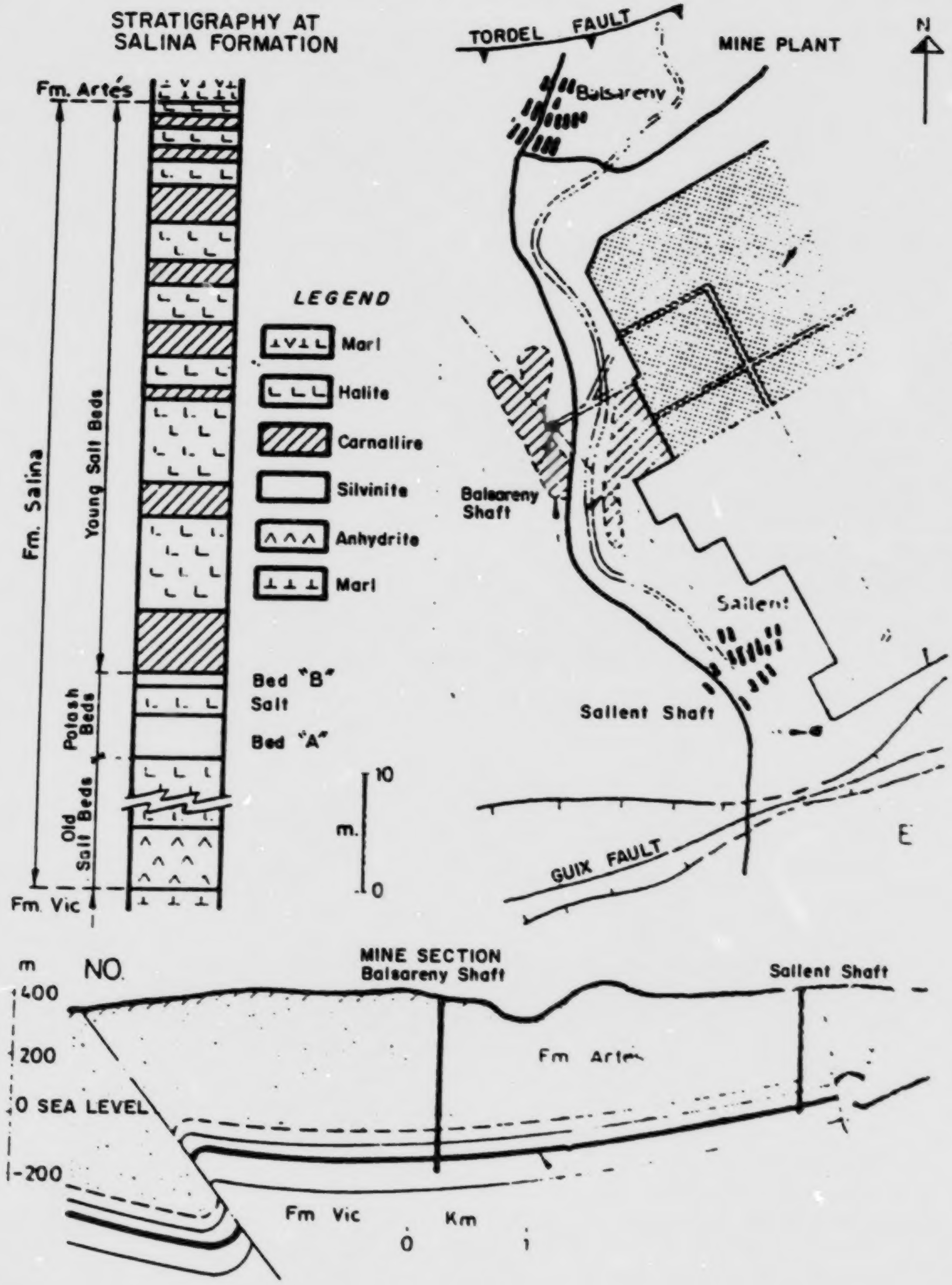

STRATIGRAPHY AT SALINA FORMATION
Fm. Artés
Fm. Salina
Young Salt Beds
Potash Beds
Old Salt Beds
Fm. Vic
LEGEND
Marl
Halite
Carnallire
Silvinite
Anhydrite
Marl
Bed "B"
Salt
Bed "A"
10
m.
0
TORDEL FAULT
MINE PLANT
N
Balsareny
Balsareny Shaft
Sallent
Sallent Shaft
GUIX FAULT
E
m
NO.
400
200
0 SEA LEVEL
-200
MINE SECTION
Balsareny Shaft
Sallent Shaft
Fm Artes
Fm Vic
Km
0
1

FIGURE 4-46 GEOLOGICAL SECTION AND STRATIGRAPHY - LLOBREGAT MINE

The carnallite is a competent seam that can be drilled with rotary machines and provides a good roof when resin bolted with 1.5 m roof-bolts. The upper sylvinite is friable and is only self supporting over a limited span, while the lower seam is soft and easily cut by the continuous miners. The underlying salt strata is fairly hard and provides a good surface on which to operate the shuttle cars.

Mining is highly mechanized, using continuous miners throughout and an automatic conveyor system.

The mining method employed is chevron room and pillar, the rooms forming a herringbone pattern (Fig. 4-47). The present mining area is a rectangular block some 800 meters wide and two kilometers long. It is the second of five such blocks to be mined and lies to the northeast of Sallent.

The block is divided lengthways by three drivages that provide haulage and ventilation services. On either side of these central service roads, ten room panels are laid out with two entries to each panel. Rooms 150 metres deep are mined at 135° from each of the panel entries and extracted on retreat.

The panel entries are driven in the upper sylvinite seam and the salt. Thus the carnallite, which is resin bolted, forms the roof. One of the entries carries the section's conveyor belt and the return air, during development; the other serves as a supply road and air intake. The two entries are driven about 400 metres into the room panel and then each is turned outwards at 45° and advanced almost to the boundaries of the panel before straightening and continuing to the end of the panel. The triangular block formed in this way at the end of each panel is developed in the upper sylvinite and the salt. The lower sylvinite is mined after ramping down from the belt entry. Development and mining of this triangle establishes the retreat plan for the rooms.

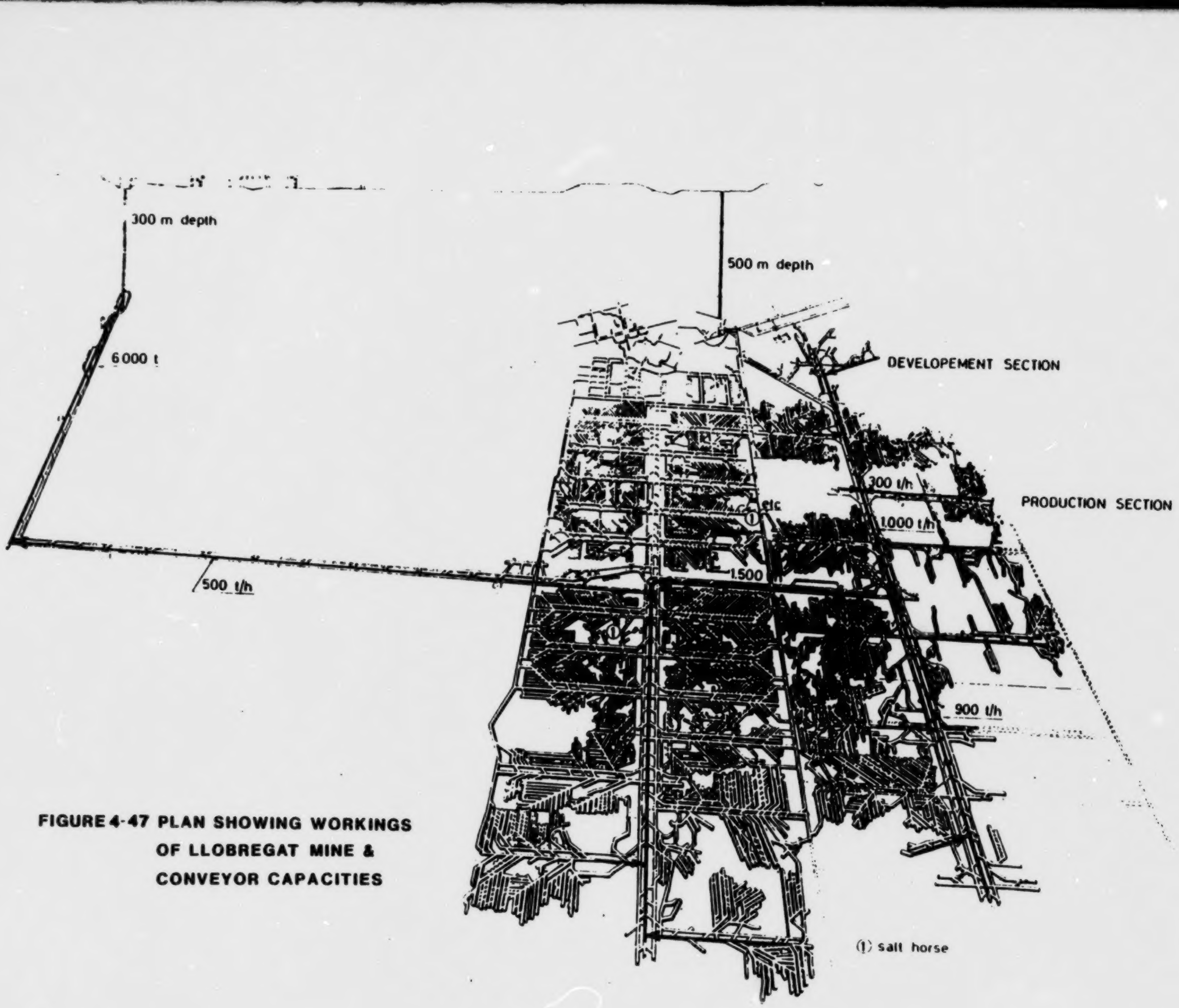

300 m depth
500 m depth
6000 t
DEVELOPEMENT SECTION
300 t/h
PRODUCTION SECTION
1.000 t/h
etc
①
1.500
500 t/h
①
900 t/h
① salt horse

FIGURE 4-47 PLAN SHOWING WORKINGS OF LLOBREGAT MINE & CONVEYOR CAPACITIES

All the mining and development is carried out by continuous miners backed up by shuttle cars. Allowing for variations dictated by the particular conditions in any one area, the general mining plan is to mine the rooms in the upper sylvinite and salt and then ramp down in the belt entry and crosscut to mine the lower sylvinite in the entries and rooms.

Where ripperhead continuous miners are used, (Fig. 4-48) the whole section (6 m) is mined in two lifts with the whole product (ore and rocksalt) being transferred by the shuttlecars to the section belt. However, with the introduction of the roadheader type continuous miners such as the Alpine SM100, the two metre rock salt band is cut out separately, loaded into a shuttle car and transported to a room where mining is completed and dumped. In this way, not only is waste salt retained underground, requiring less surface storage and also improving the potash grade delivered to the process plant, but additional capacity is made available in the transportation system to enable output to be increased and productivity and costs improved (Fig. 4-49).

From this point on, the removal of the ore from underground to the processing plant is fully automatic. Each section is served by one conveyor belt that serves all the rooms of the panel. This belt in turn feeds onto two belt conveyors in the entries running down the centre of the panel block. They collect the output of each panel and carry it to a centrally situated silo of 1,000 tonne capacity. The silo was mined out of the sylvinite and salt.

At the base of the silo is a crusher installation equipped with two crushers. Crushed ore is fed from here to the main conveyor system. This system runs through the basal rock salt 20 metres below the sylvinite beds and comprises four flights with a total length of 4 kilometres. Ore is transported to the main storage silo at the bottom of Sallent Shaft.

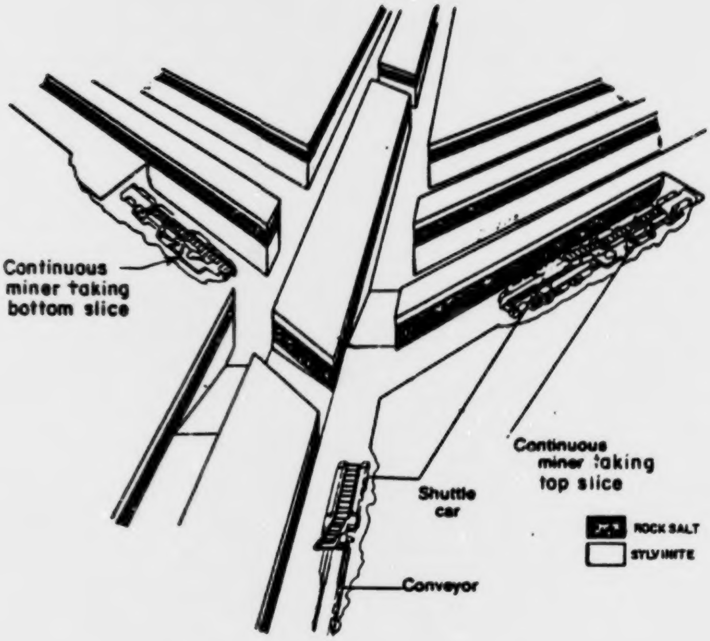

Continuous miner taking bottom slice
Continuous miner taking top slice
Shuttle car
Conveyor
■ ROCK SALT
□ SYLVINITE

FIGURE 4-48 DIAGRAM SHOWING
TWO LIFT METHOD OF MINING

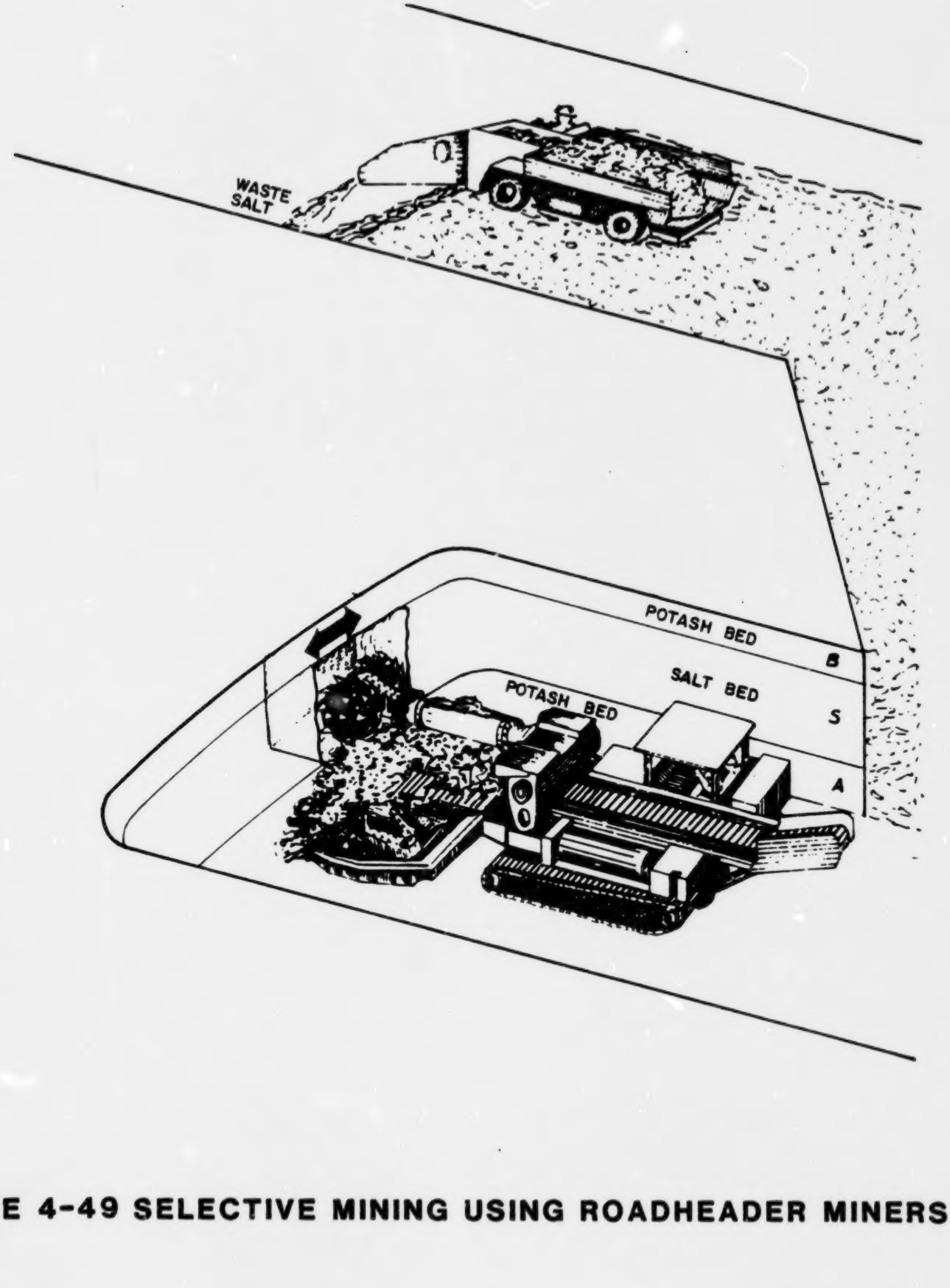

WASTE
SALT
POTASH BED
B
SALT BED
S
POTASH BED
A

FIGURE 4-49 SELECTIVE MINING USING ROADHEADER MINERS

The 7000 tonne silo at Sallent, excavated in the salt and sylvinite beds, performs a very useful buffer function. Variations in mining conditins such as undulations, barren areas and folding do not allow a uniform mining system throughout the mine. Thus, the underground silo allows a steady feed to be supplied to the plant even at times of production failures undergound. Additionally, a build up of ore underground, caused by breakdowns on the surface, can be accommodated for a limited period.

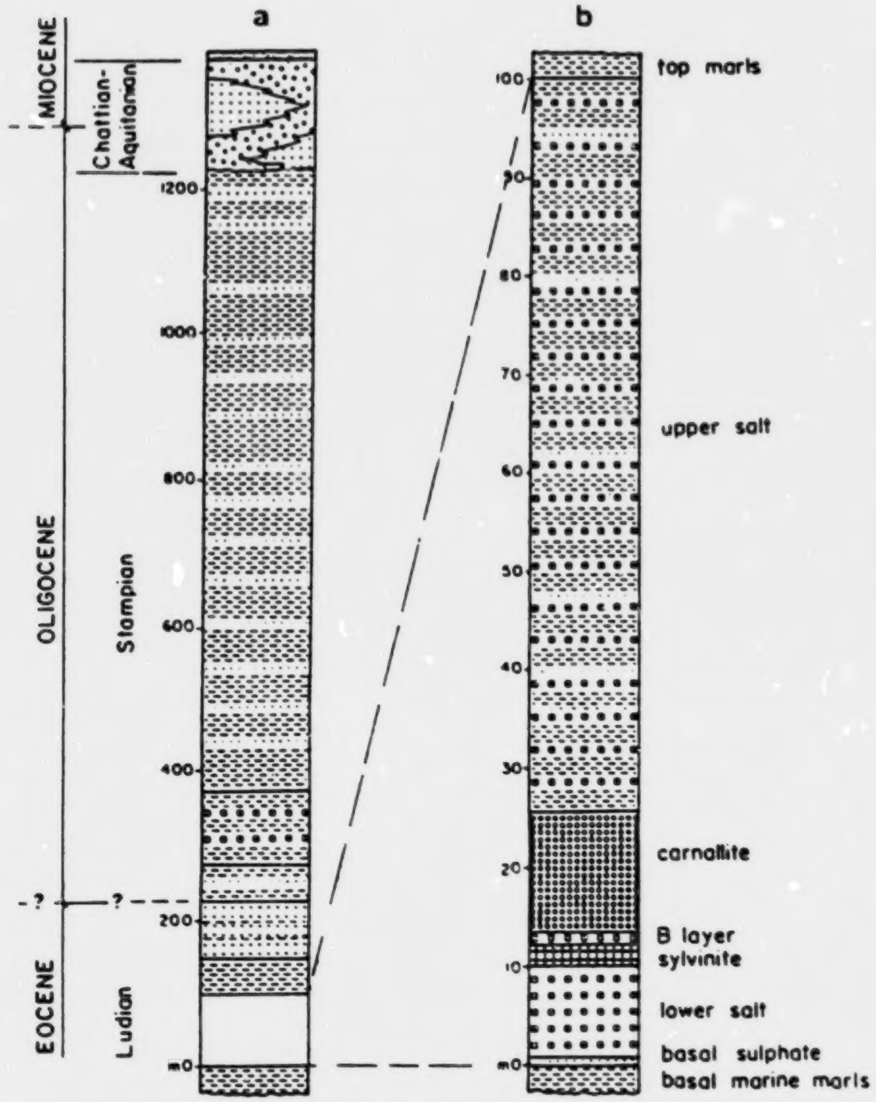
The mine works three seven-hour shifts per day, six days a week. Available working time at the face per shift is five hours.

Navarra

The Esperza mine is located south of Pamplona and is mining a relatively consistent and continuous bed of sylvinite, which dips at about 13°, but which is also affected by a series of major faults which tend to throw the seams down deeper.

The composite salt bed is nearly 15 metres thick and from the top level down comprises firstly a seam of carnallite varying between 1.0 and 2.0 metres which is separated from a 2.0 metres sylvinite seam by interposing bands of sterile salt and marl (B Layer) which together can vary from 0.25 to 1.9 metres thick. Below this sylvinite seam is again rock salt (halite) approximatey 9.0 to 10.7 metres thick which forms the working floor (Fig. 4-50).

Since its opening in 1963, the mine has been producing most of its output from advancing longwall caving faces. For the first seven years, longwall mining was only in the sylvinite seam, but from 1970-1977 both the carnallite and sylvinite were worked in close sequence. Since 1977, the mining of the carnallite seam has not been economical.


a
b
MIOCENE
OLIGOCENE
EOCENE
Chattian-Aquitanian
Stampian
Ludian
1200
1000
800
600
400
200
m0
?
?
100
90
80
70
60
50
40
30
20
10
m0
top marls
upper salt
carnallite
B layer
sylvinite
lower salt
basal sulphate
basal marine marls

a. STRATIGRAPHICAL POSITION

b. DEPOSITIONAL UNITS

FIGURE 4-50 THE SALINE FORMATION OF NAVARRA

In the early days, the potash was mined by floor mounted shearers delivering potash ore onto chain conveyors, the face being supported by powered supports and the salt roof being caved into the goaf behind the supports. These early shearers were powered by 100 kW motors and produced 150 tons per shift from 140 m to 180 m long faces. The disadvantage of the floor mounted shearer is that a greater amount of roof is exposed, and unless the roof is very good, roof control problems can be experienced.

As the workings became deeper, and also with the decision to mine the carnallite bed, the opportunity was taken to use the conveyor mounted shearer. This 400 kW machine offered better productivity, better roof control, especially in the sylvinite workings below the old carnallite faces. Output in carnallite averaged 900 tonnes per day, but in the softer sylvinite averaged 1400 tonnes per day with a peak of 2600 t. Face productivity averaged 82 tonnes per manshift.

Since 1979 the mine has been working in the south zone (Zone Sur) which due to a combination of downthrow faulting, seam gradient and surface topography, is considerably deeper than had been previously worked (Fig. 4-51).

Because of the increased depth, the support capacity has been increased from 4 x 20 t to 4 x 120 t per chock and the face lengths increased to 210-270 m to reduce the losses due to sterilization of reserves in pillars between faces. The 400 kW shearers are averaging 1750 tonnes per day, peaking at 2500 tpd. Monthly production is now exceeding 150000 t per face. Future prospects using such equipment as the 750 kW shearer now in use in trona in USA, are for average outputs in potash of between 3000 and 3500 tones per day.

The longwall faces are equipped with double ended ranging drum shearers (Anderson Strathclyde or Eickhoff) using water for dust

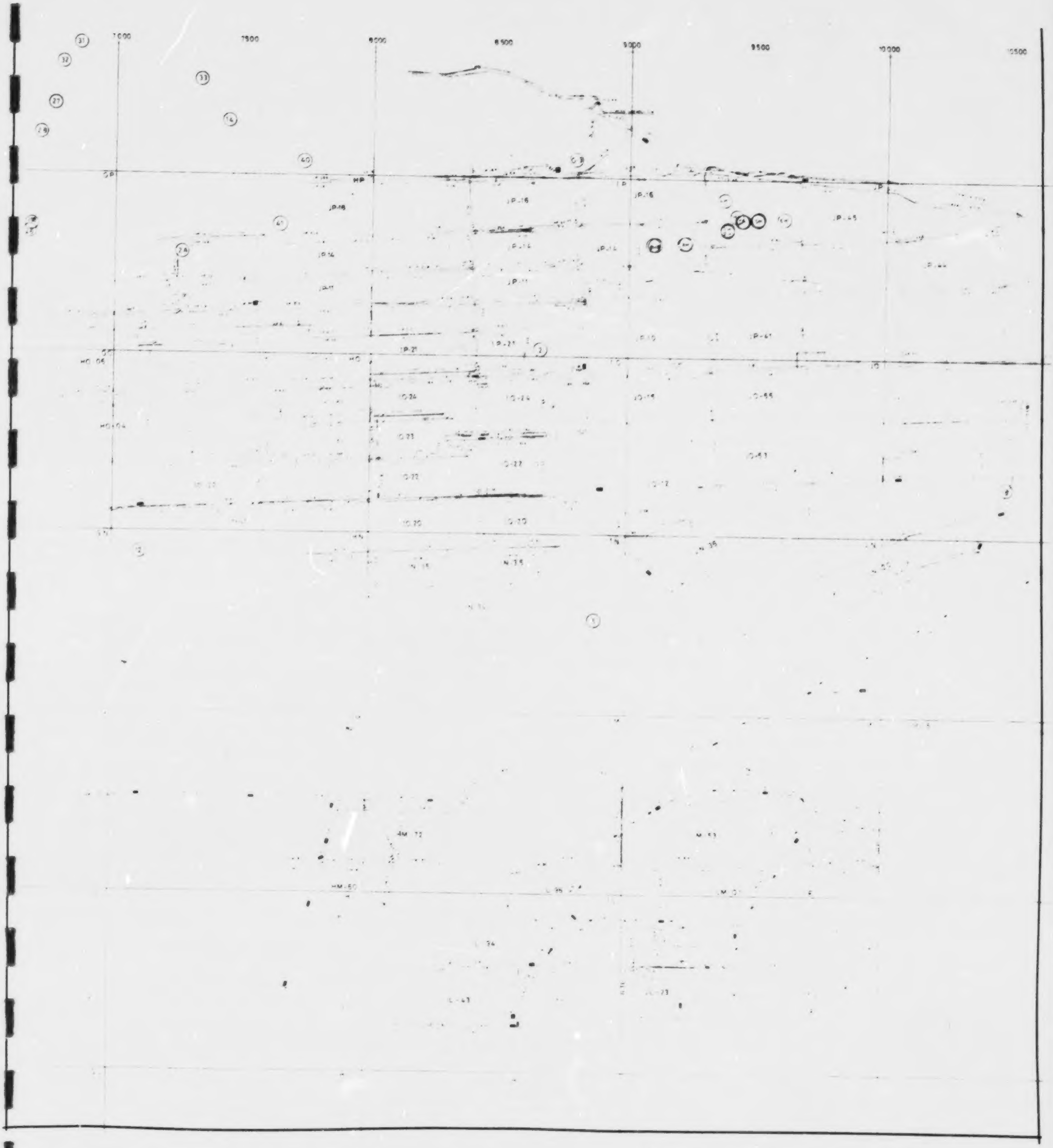

7000
7500
8000
8500
9000
9500
10000
10500

FIGURE 4-51 PLAN OF LONGWALL WORKINGS POTASAS DE NAVARRA

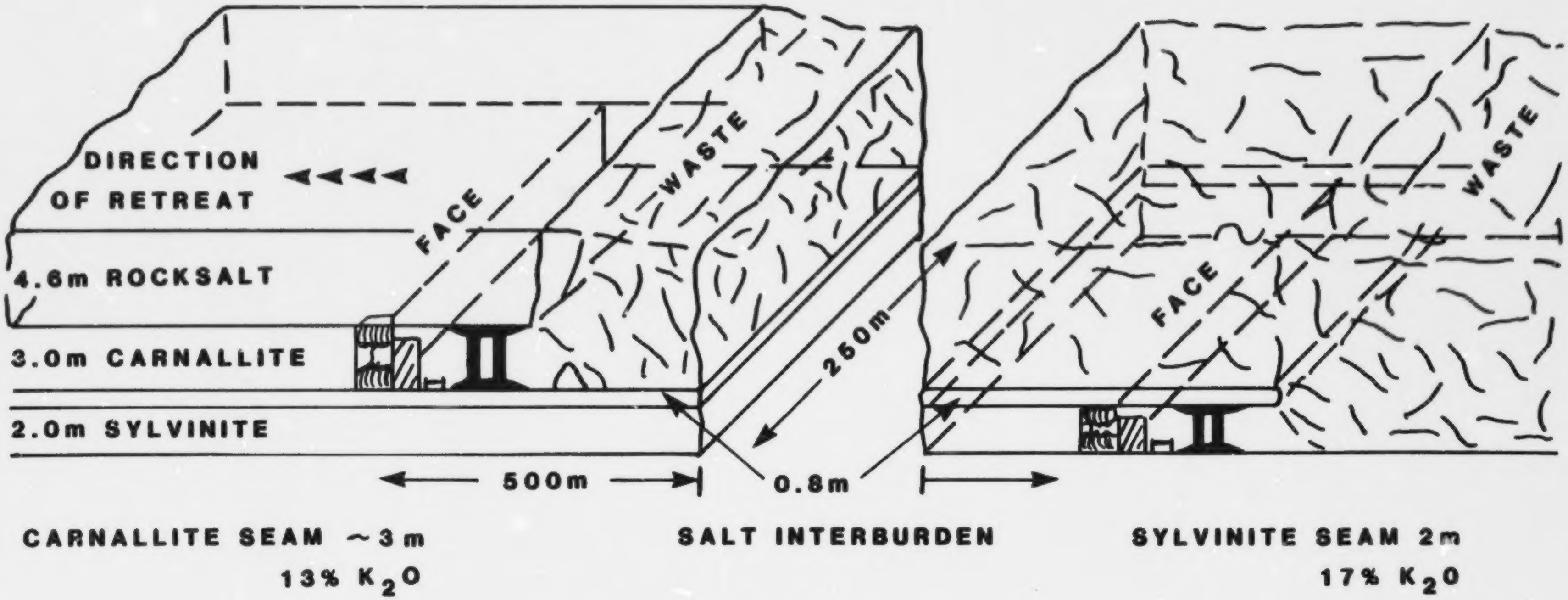
suppression, and load sensors to ensure that the optimum cutting rate is achieved. Roof support is provided by shield type powered supports. However the nature of the salt above the seams is such that, in order to prevent the severe bumps which occur if the roof does not regularly cave, it is necessary to drill and blast the roof to induce caving. (Explosive consumption is about 23 kgs per 1000 tonnes of potash ore mined). Up to seven longwalls are worked at any one time, each face requiring eight men per shift for a face productivity of over 52 tonnes per manshift.

When the two seams were simultaneously worked, the top face in carnallite was mined first, cutting between 3.0 and 3.4 m seam height and allowing the salt roof to cave behind. The second face in the sylvinite, mining approximately 2.0 m height with 0.7-0.8 m of rocksalt as the immediate roof to the carnallite face waste, follows some 500 metres behind the first face (Fig. 4-52).

Development at the mine has been by the ripperhead type continuous miners, roadways being typically 4.0 m wide by 3.4 m high supported by rock bolts set at a density of about $1.0/m^2$. In the deeper south zone, arch shaped roadways are becoming necessary, mined by roadheader type miners, and supported by rock bolts or in certain areas of the mine, steel arches.

Another geological aspect of obvious interest in this PDN field is the presence of very extensive water-bearing strata above the salt deposits. This comprises a thick sandstone structure holding large quantities of water which one would expect to have serious consequences for both the safety and the acceptability of certain methods of working; e.g. longwall. It has been found however that, even working caving longwall, the overlying water does not seriously penetrate the mine workings because there are several layers of thick impervious strata e.g. clay and marl, between the water bearing sandstone and the roof of

FIGURE 4-52 SIMULTANEOUS MINING OF TWO SEAMS BY LONGWALL CAVING POTASAS DE NAVARRA - SPAIN


DIRECTION OF RETREAT
FACE
WASTE
4.6m ROCKSALT
3.0m CARNALLITE
2.0m SYLVINITE
250m
FACE
WASTE
500m
0.8m
CARNALLITE SEAM ~3m
13% K2O
SALT INTERBURDEN
SYLVINITE SEAM 2m
17% K2O

PRINCIPAL FACE CHARACTERISTICS

1. ANDERSON BOYES DOUBLE ENDED RANGING DRUM SHEARER
1. WESTPHALIA CHAIN CONVEYOR
250 MARRELL 4-LEG 80t CHOCKS
MANNING 8 MEN/SHIFT
OUTPUT 1000t PER 3 SHIFTS
42t PER MANSHIFT

the salt deposit. It would seem that when any cracks or fissures occur in the overlying strata this allows seepage of water into these interbedded layers of clay and marl. These materials, when in contact with the water, plastically deform and/or expand so that they effectively seal the cracks and fissures thus preventing the water from reaching the salt beds. Although the overlying water bearing strata are treated with considerable caution, it has been possible to mine individually a top carnallite seam and a bottom sylvinite seam two metres below and even mine the sylvinite below old carnallite workings without major water problems.

All access to the Navarra workings is through inclined drifts at 15-18% gradient. The workings in the South Zone are now more than five kilometres from the surface. In order to reduce travelling time, a telelift (ski type) system is employed travelling at a speed of 3 metres per second with a capacity of 800 men per hour. Materials are handled by monorail systems.

483 GEOTECHNICAL ASPECTS

Potash mining is undertaken in Spain using room and pillar, sublevel open stoping and longwall mining methods at individual mines Room and pillar mines at Llobregat uses a long room mining system with no pillar extraction, producing an extraction ratio of approximately 50%. The seams being mined form part of a sub-horizontal bedded deposit with the potash being overlain by approximately 100 m of interbedded halite and carnallite.

A salt seam typically 2.5 m thick separates the two potash seams that are mined. The salt is mined and placed in the rooms as backfill. The fill however does not play a significant structural role in supporting to roof. The production rooms are typically seven metres wide by 120 to 450 m long and are separated by pillars three metres wide. Most of the rooms are mined at an angle of approximately 45° to the sub-entries. Salt horses form additional major pillars in the mine. Both resin grouted bolts and mechanically anchored bolts are used in the mine and the main entries are rockbolted on a regular one metre by one metre pattern. Typical long term convergence in the mine is approximately 145 mm per year and the maximum subsidence recorded on surface is approximately 0.5 m. Surface subsidence does not pose a present problem nor is it recognized as a potential problem in the future.

A sublevel open stoping system is used to mine the dome deposit at Cardona at depths between 500 m and 1000 m below surface. The potash seams are intensely folded as a result of the dome rising through the overlying sediments and the actual seams being mined are steeply dipping. There are no major aquifers adjacent to the mining activity. A wide range of stope sizes has been adopted to conform to the irregular nature of the deposit. Long term convergence in the mined out areas is typically 145 mm per year and the maximum subsidence that has been recorded on surface is one metre.

At the Navarra potash mine, several interesting geotechnical problems have been resolved, problems which arose due to the rapid increase in mining depth.

At the shallower depths, development roadways were driven in the sylvinite and the rock salt (compressive strength 45-55 Mpa) using ripperhead continuous miners to produce rectangular section roadways. At the increased depths in the South Zone, stress concentrations at the junctions and walls of the roadway are such that the roadways are deteriorating with consequent maintenance problems. Conditions were improved by having development openings with a semi-circular roof section (Fig. 4-53). The change in section means that roadways now have to be driven by roadheader type miners.

Roof support in roadways is another area of change. Roof support is usually provided by resin anchored bolts. PDN installs over 80 000 per year. The capacity of the bolts used in the shallow (300-500 m) zone was seven tonnes, but this has had to be increased to 19 tonnes in the deep south zone (1300 m). This increase was the result of extensive insitu testing.

Extensive convergence measurements are taken at PDN. The new design of roadway in the south zone has enabled convergence to be limited to 300 mm in the first year (10% of the initial height). It has also been found that lateral convergence of the walls is more than five times greater in the south zone than in the shallower zones. Roof convergence in the roadway increases from 75 mm per metre to 150 mm per metre as the longwall face is advanced.

On the longwall faces at the 1200-1300 m depth, the loads imposed on the face supports are naturally increased. However, the increased strata loadings have resulted in the natural cave of the roof strata taking place some 25 metres behind the face instead of 70 metres. This is still too far, so explosives are still used to induce the cave, but consumption has almost halved (23 to 14 kgs/1000 t).

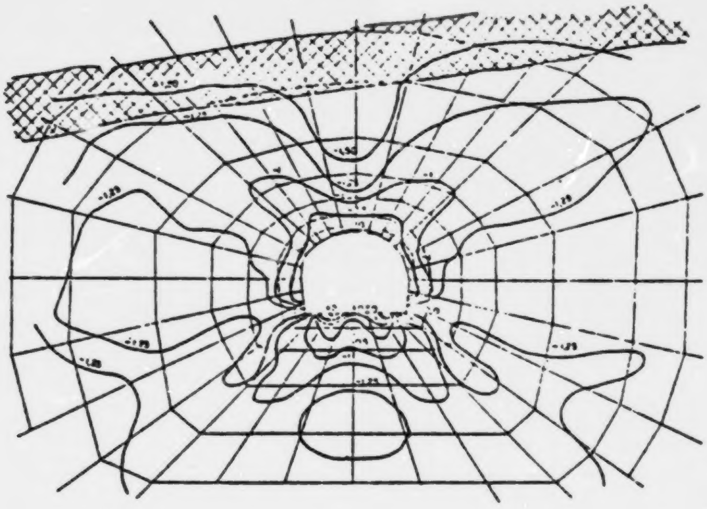

-1.50
-1.25
-1.25
-1.25
-1.25
-1.25

FIGURE 4-53 STRESS DISTRIBUTION ROUND SEMI-CIRCULAR ROADWAY AT 1300m DEPTH

4.9 ITALY

491 GEOLOGICAL ASPECTS

Potash deposits in central Sicily are associated with the Solfifera Series of Late Miocene age. The basin of accumulation of the evaporitic succession is referred to as the Caltaniseetta trough or Central Sicilian Basin and this feature extends from Nicosia southwest into the Mediterranean. Current interpretations recognize marginal and trough sedimentary units. A basal diatomaceous marl occurs across the entire region and is referred to as the Tripoli Formation. The overlying Cattolica gypsum beds are developed in the basinal trough. Gypsum turbidites occur above these strata. The Basal Limestone beds overlie the Tripoli Formation in the marginal area and are thought to be comtemporaneous in development with the main gypsum beds in the basin centre. Halite and potash strata ranging in thickness between 400 and 500 metres occur at the top of the series (Fig. 4-54).

The salt section is immediately overlain by alternating beds of laminated gypsum and marl. Four main zones are recognized within the halite and potash unit. These are designated zones A to D in ascending order with Zone B containing the commercial potash deposits.

Kainite is the principal potash mineral present in the Sicilian deposits. Individual beds may be correlated over considerable distances although there has been structural isolation of potash into several occurences across the area. Associated potash minerals include carnallite, sylvite, kieserite and bischofite.

There are generally six kainite beds with an average of 10-16% K_2O with additional poorer mineralized beds. The tectonic disturbance which isolated the potash deposits resulted in deformation and in parti-

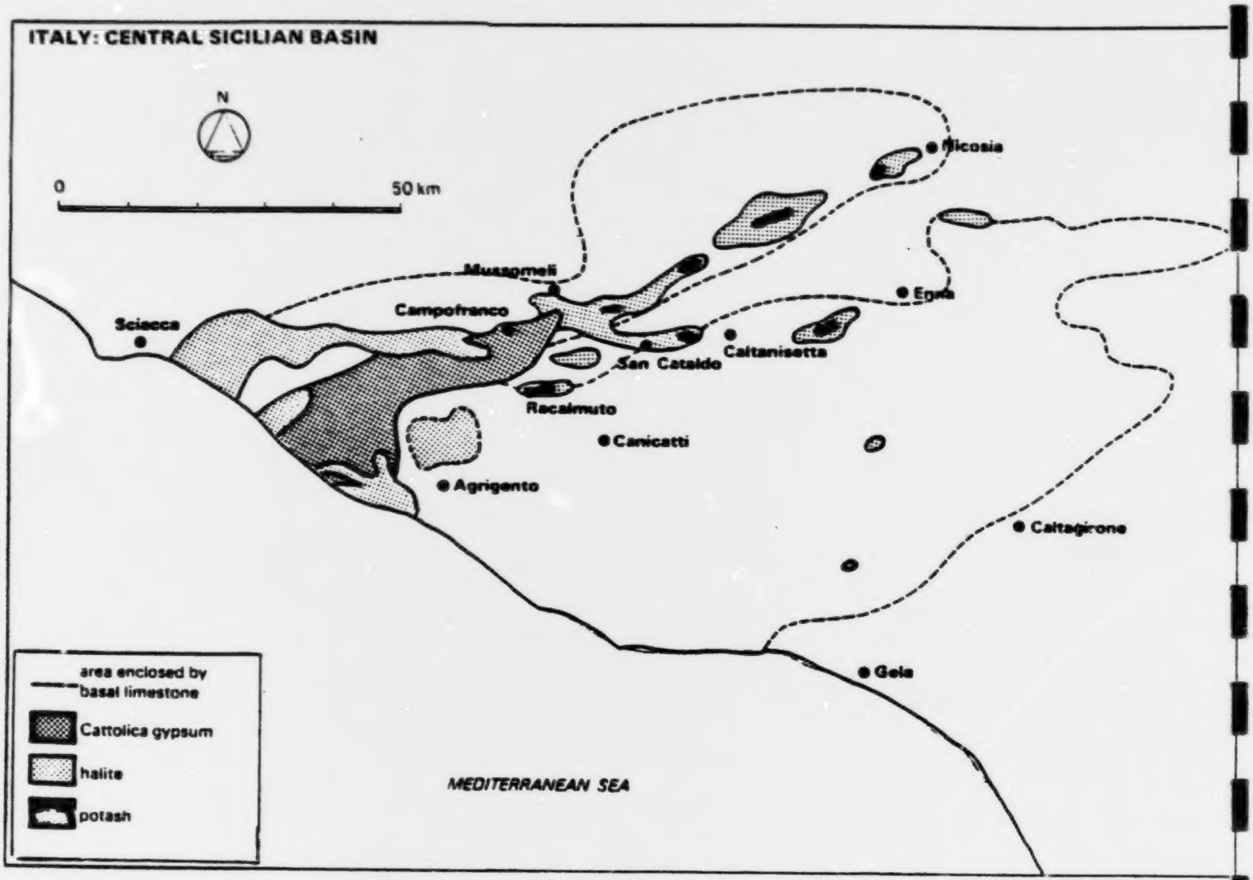

ITALY: CENTRAL SICILIAN BASIN
N
0
50 km
Nicosia
Mussomeli
Enna
Campofranco
Sciacca
San Cataldo
Caltanisetta
Racalmuto
Canicatti
Agrigento
Caltagirone
Gela
MEDITERRANEAN SEA
area enclosed by basal limestone
Cattolica gypsum
halite
potash

FIGURE 4-54 REGIONAL GEOLOGY SICILY

cular, thickening of the beds in anticlinal structures. The Kainite beds of economic interest can thus reach up to 35 m in thickness and are often up to 5 m thick. Rock salt beds appear to be somewhat thinner, up to one metre thick. Insoluble material is present in the form of anhydrite or clays but rarely excees 0.8% of the ore.

At the San Cataldo mine, the potash beds exhibit regular bedding, but at the Palo mine some 3 km away, the basin is very disturbed, (Fig. 4-55). At the Racalmuto Mine, the deposit is approximately elliptical 4 km x 2 km - and consists of rock salt and kainite beds. Due to the effect of lateral pressures, the original sub horizontal layers have folded into anticlinal structures. Mining occurs in the thicker deposits on the crests. The Pasquasia mine is located in the largest potash basin in Sicily extending some 8 km x 3 km. Kainite mineralization consits of five beds of mineable thickness and grade, dipping at between 25° and 30° and relatively constant across the basin.

At the Realmonte mine, the mineralization lies in an anticline, some 150 m below the surface. The beds lie at 60-65° with an average thickness of five metres.

492 MINING METHODS

Mining is generally undertaken by room and pillar methods using both continuous miner (Joy) and drill and blast methods, although sub-level stoping and block caving are also practised.

At the San Cataldo mine, early room and pillar mining was by drill/blast methods with drill jumobs, gathering arm loaders and diesel shuttle cars delivering to conveyor or rail haulage systems. Joy continuous miners were later introduced, and this, in fact, was the

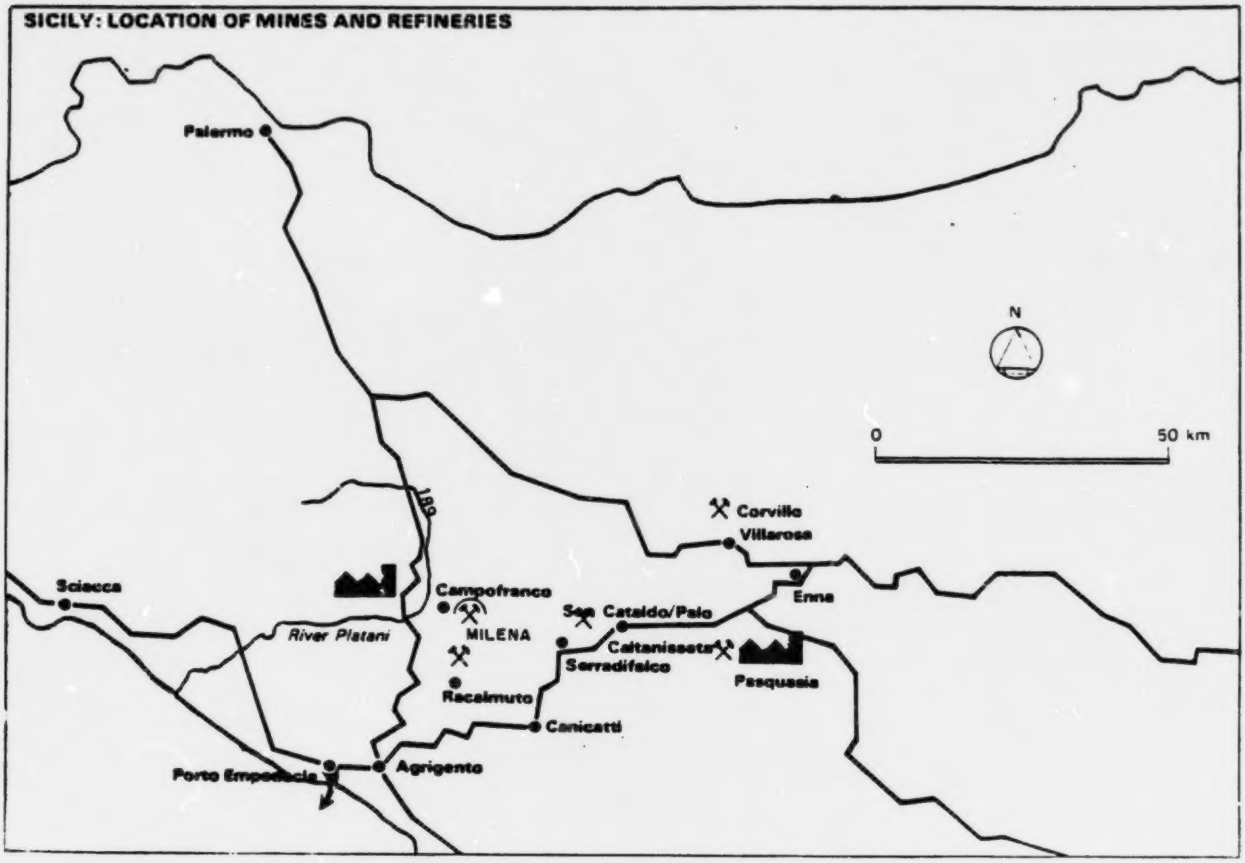

SICILY: LOCATION OF MINES AND REFINERIES
Palermo
N
0
50 km
189
Corvillo
Villarosa
Sciacca
Campofranco
MILENA
San Cataldo/Palo
Enna
River Platani
Caltanissetta
Serradifalco
Pasquasia
Racalmuto
Canicatti
Porto Empedocle
Agrigento

FIGURE 4-55 LOCATION OF POTASH MINES- SICILY

equipment used at the Palo mine from the commencement of the room and pillar mining practised there.

At the Pasquasia mine, (Fig. 4-56) room and pillar is again the principle method used with drill/blast equipment to extract the ore in the thick seam rooms, whilst continuous miners are employed for the development. In the deeper parts of the mine, the sylvinite ore is mined by the block caving system. At the Racalmuto mine, room and pillar mining is practised but, because of the seam gradients , is incorporated into a sub-level system. The sub-levels are eight metres apart. Three sublevels are mined then the fourth is left as a pillar. Pillars are 30 m square in the sylvinite and 20 m square in the carnallite beds. The length of the room mined off the panel entry is dependent on the width of the deposit.

At the Realmonte mine, the steep gradients (60-65%) and seam thickness (5 m) enable the sublevel stoping system to be used incorporating drill blast methods. Ore is loaded by LHD units from the stopes into trucks which travel out of the mine on an 8° slope from the 150 m deep main level.

No information is available about the mining methods employed at the Corvill mine, or intended for the developing Milena mine.

Geotechnical information is similarly not available for the Sicilian potash mining operations. They do not appear to have severe problems since support for the roof is rarely required, and recovery rates are relatively good.

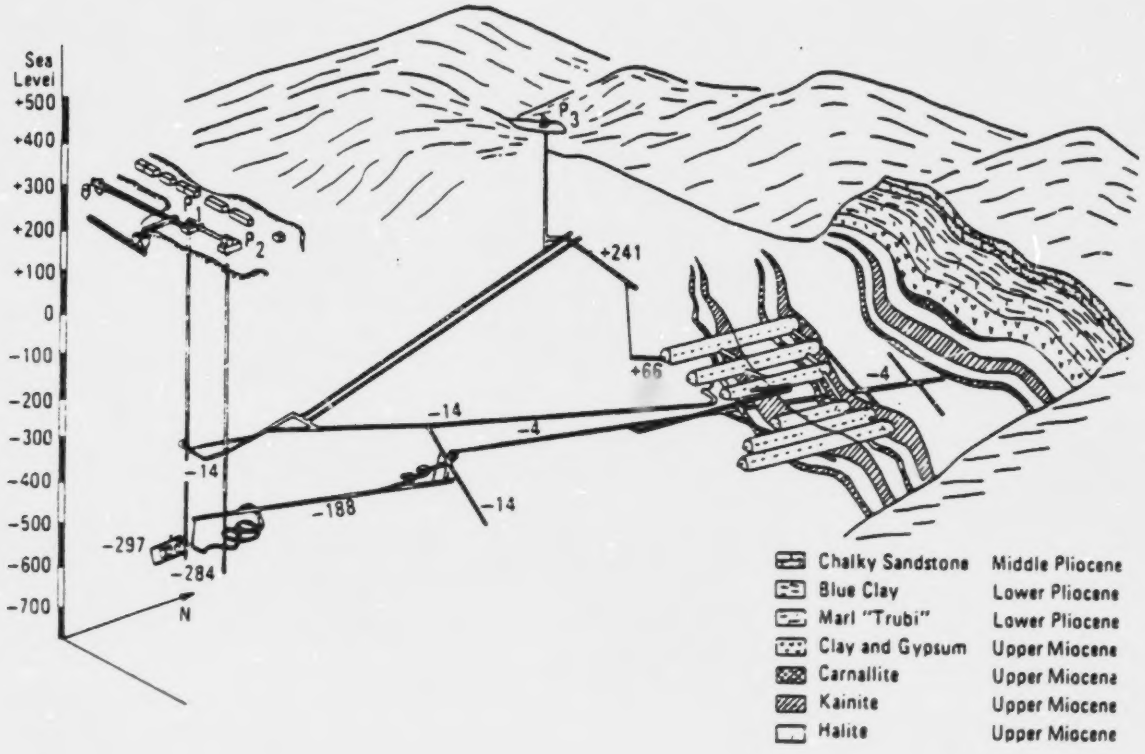

Sea Level
+500
+400
+300
+200
+100
0
-100
-200
-300
-400
-500
-600
-700
P_1
P_2
P_3
+241
+66
-4
-14
-4
-14
-14
-188
-14
-297
-284
N
Chalky Sandstone Middle Pliocene
Blue Clay Lower Pliocene
Marl "Trubi" Lower Pliocene
Clay and Gypsum Upper Miocene
Carnallite Upper Miocene
Kainite Upper Miocene
Halite Upper Miocene

FIGURE 4-56 LONG ROOM & PILLAR MINING IN STEEP SEAMS PASQUASIA MINE

4.10 U.S.S.R.

4101 GEOLOGICAL ASPECTS

Potash deposits of three different ages (Fig. 4-57) are exploited in the U.S.S.R.:

1. Upper Devonian sources in the Pripyat Depression of the Byelorussia region.

2. Permian beds of the Upper Kama Basin west of the Ural Mountains.

3. Miocene potash deposits in the pre-Carpathian area of the western Ukraine.

Upper Devonian (Fig. 4-58)

An extensive inland sea covered much of central U.S.S.R. in Fammenian times and it extended westward onto the Russian platform in two main embayments. To the north in the region of the Moscow Depression extensive sediments accumulated but no potash salts were deposited. Two series of salt-bearing strata are present with a combined thickness of up to 300 metres. Commercial potash zones are found in the upper saline series within the Pripyat Depression at the west end of the main basin. Here the succession is comprised of alternating beds of salt, marl, and shale. There are up to six salt beds which include interbeds or lenses of potash. Four main potash zones have been identified and are numbered Layers I to IV from top to base. Layers II and the lower part of III are presently under production at Soligorsk. The upper part of Layer III above the ore zone includes a carnallitic sylvinite immediately overlain by a low grade sylvinite. Argillaceous carbo-

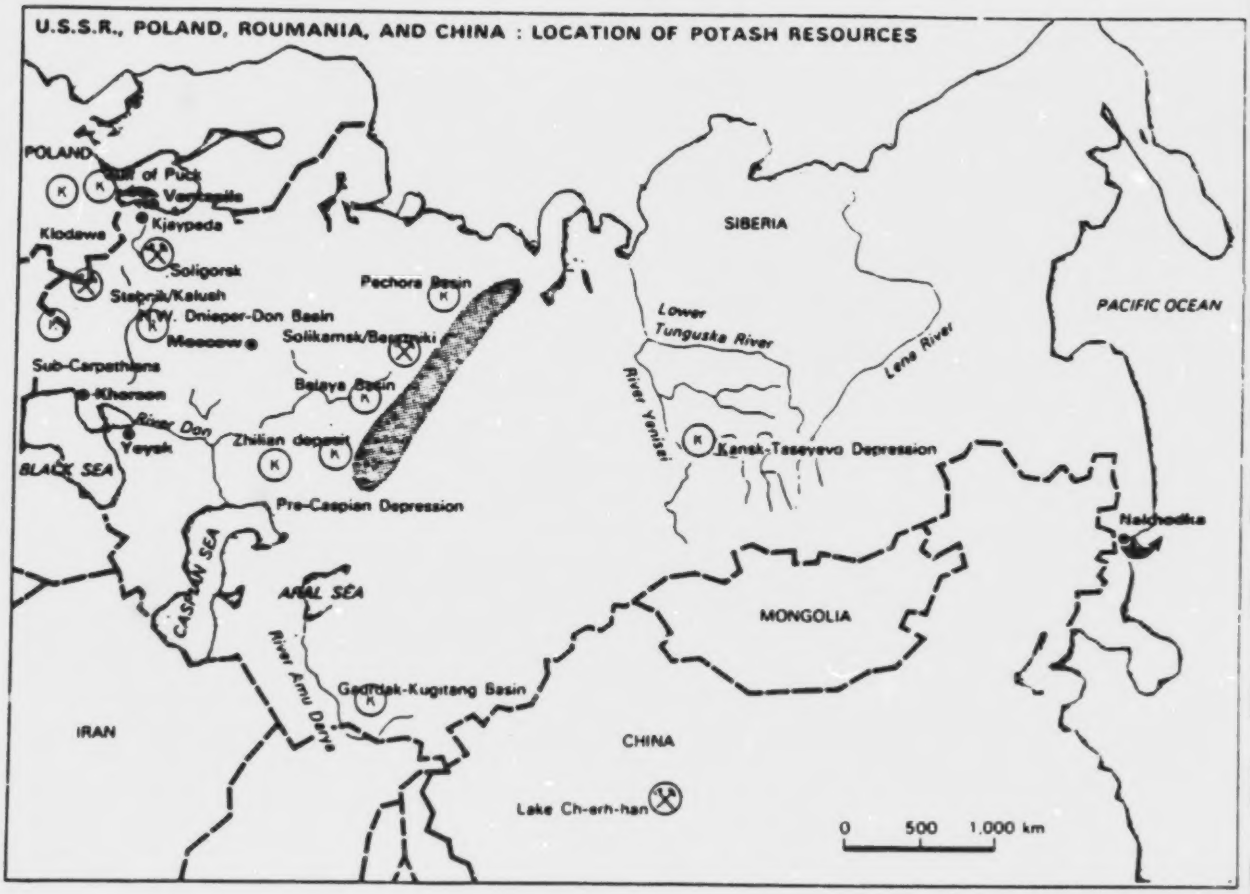

U.S.S.R., POLAND, ROUMANIA, AND CHINA : LOCATION OF POTASH RESOURCES
POLAND
Gulf of Puck
Ventspils
Kjaypeda
Klodawa
Soligorsk
Stebnik/Kalush
N.W. Dnieper-Don Basin
Moscow
Sub-Carpathians
Kherson
River Don
Yeysk
BLACK SEA
Pechora Basin
Solikamsk/Berezniki
Belaya Basin
Zhilian deposit
Pre-Caspian Depression
CASPIAN SEA
ARAL SEA
River Amu Darya
Gaurdak-Kugitang Basin
IRAN
SIBERIA
Lower Tunguska River
River Yenisei
Lena River
Kansk-Taseyevo Depression
MONGOLIA
CHINA
Lake Ch-erh-han
Nakhodka
PACIFIC OCEAN
0
500
1,000 km
K

FIGURE 4-57 LOCATION OF POTASH REGIONS U.S.S.R.

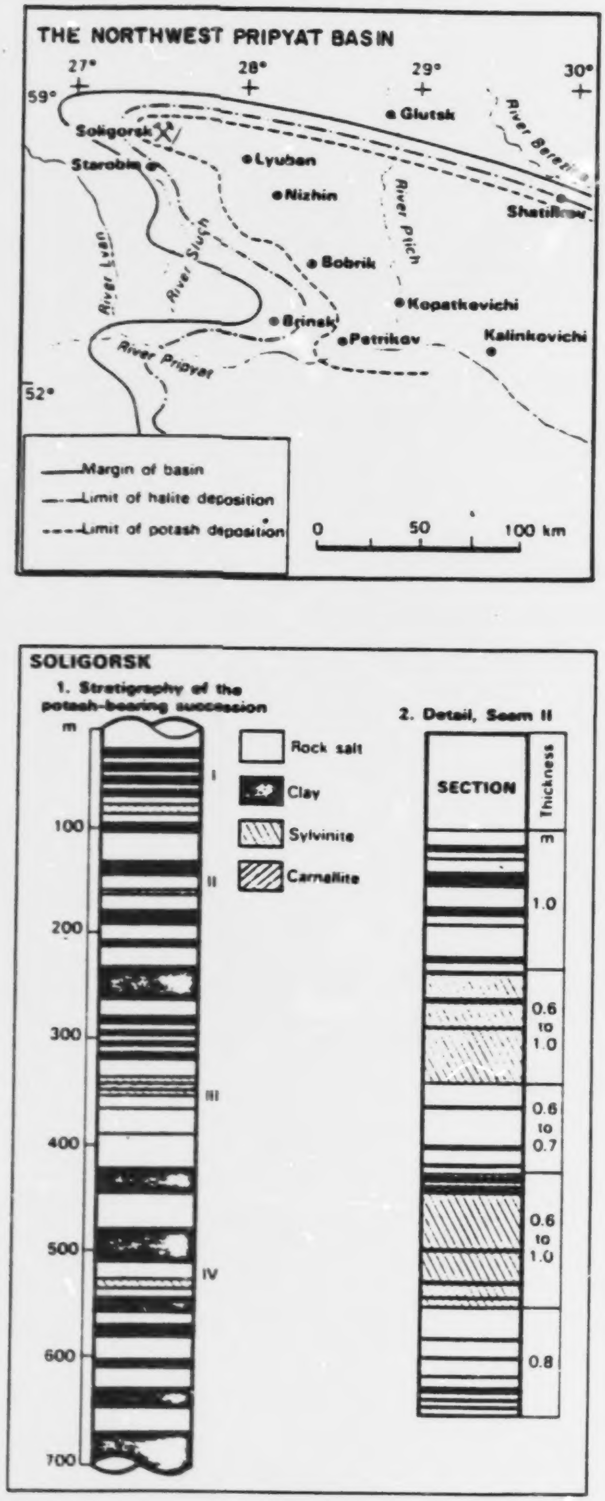

THE NORTHWEST PRIPYAT BASIN
27°
28°
29°
30°
59°
52°
Soligorsk
Starobin
Lyuban
Nizhin
Glutsk
River Berezina
Shatilkov
River Ptich
Bobrik
Kopatkevichi
Kalinkovichi
Brinsk
Petrikov
River Pripyat
River Lyan
River Sluch
Margin of basin
Limit of halite deposition
Limit of potash deposition
0
50
100 km
SOLIGORSK
1. Stratigraphy of the potash-bearing succession
m
100
200
300
400
500
600
700
I
II
III
IV
Rock salt
Clay
Sylvinite
Carnallite
2. Detail, Seam II
SECTION
Thickness
m
1.0
0.6 to 1.0
0.6 to 0.7
0.6 to 1.0
0.8

FIGURE 4-58 LOCATION & STRATIGRAPHY OF POTASH DEPOSITS - PRIPYAT BASIN - SOLIGORSK MINE

nates and sulfates 245 to 445 metres thick occur above the upper salt series. The uppermost strata of this unit and the younger overlying sediments are water-bearing.

Permian (Fig. 4-59)

A major sedimentary basin developed during the Carboniferous within the Russian platform region. Confinement was achieved to the east through uplift of the Urals, to the south by means of the Donets-Mangyshlak tectonic belt, and to the east as a result of uplift on the western sector of the Russian platform itself. An elongated north-south trough having a narrow connection to the open sea to the north was well developed by the early Permian. Halite and potash deposition took place in several isolated basins along the length of the trough. Potash mining is presently underway in the Upper Kama Basin region. The area of potash-bearing deposits is approximately 110 kilometres long, from north to south, and 40 kilometres wide.

Basal Permian beds within the basin include 40 metres of clays and calcareous strata overlain in turn by 380 metres of shales and anhydrites. Above these beds are 250 to 400 metres of salt with a 120 metre thick potash zone above.

The potash-rich interval has 26 to 30 metres of sylvinite at the base. A carnallitic zone 70 to 80 metres thick occurs above the sylvinite. A thin sylvinite layer is present above the carnallite in places.

The basal sylvinite has five to seven layers each of which is 0.5 to 10 metres thick and separated by salt bands one to 4.5 metres in thickness. The uppermost sylvite bed (Bed A) is mined in conjunction with the lowermost bed of the carnallitic zone (Bed B). Another principal zone exploited is the Red II sylvinite a few metres below. It is

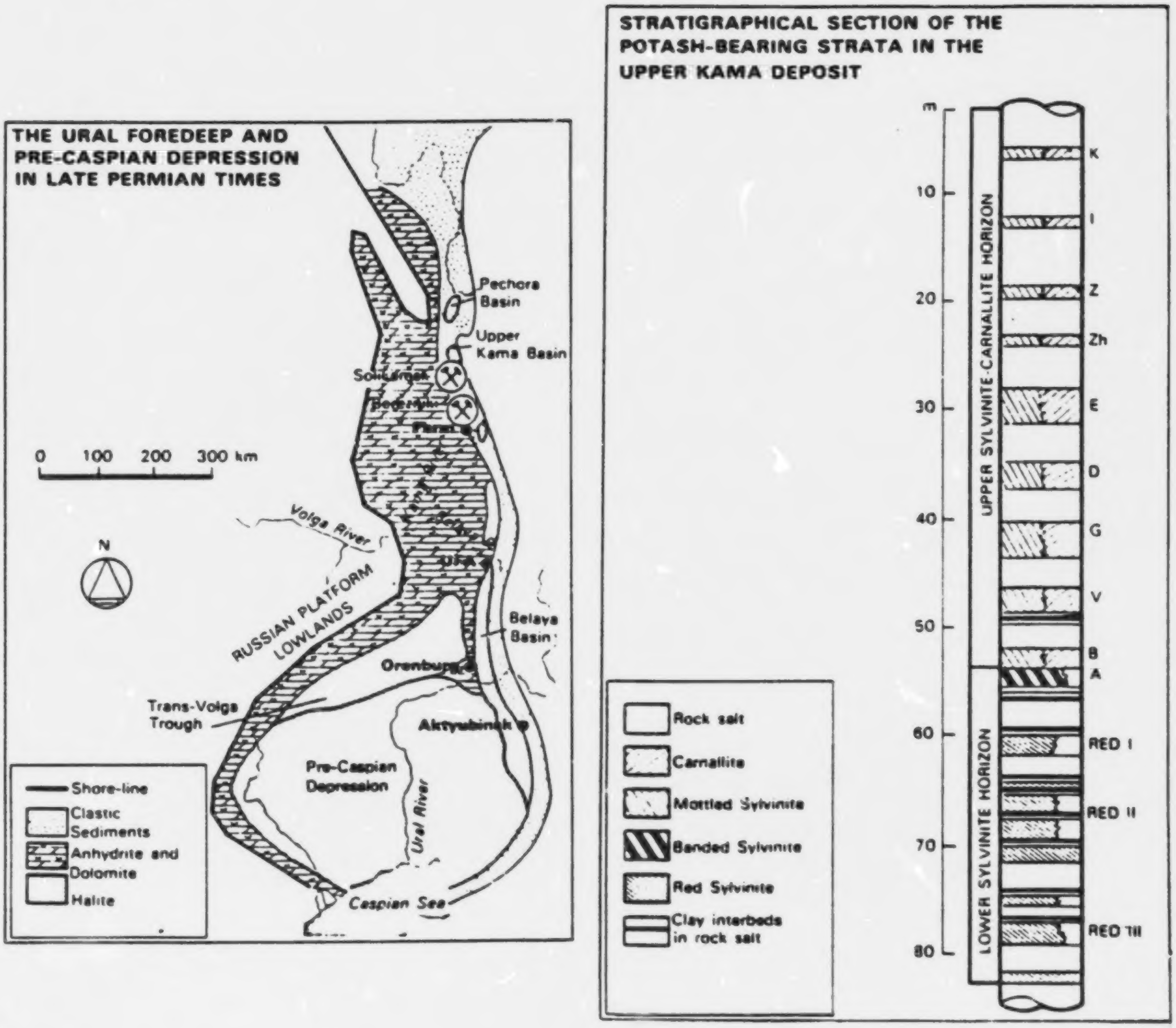

THE URAL FOREDEEP AND PRE-CASPIAN DEPRESSION IN LATE PERMIAN TIMES
Pechora Basin
Upper Kama Basin
Solikamsk
Berezniki
Perm
0 100 200 300 km
N
Volga River
Ufa
RUSSIAN PLATFORM LOWLANDS
Belaya Basin
Orenburg
Trans-Volga Trough
Aktyubinsk
Pre-Caspian Depression
Ural River
Caspian Sea
Shore-line
Clastic Sediments
Anhydrite and Dolomite
Halite
STRATIGRAPHICAL SECTION OF THE POTASH-BEARING STRATA IN THE UPPER KAMA DEPOSIT
m
10
20
30
40
50
60
70
80
UPPER SYLVINITE-CARNALLITE HORIZON
LOWER SYLVINITE HORIZON
K
I
Z
Zh
E
D
G
V
B
A
RED I
RED II
RED III
Rock salt
Carnallite
Mottled Sylvinite
Banded Sylvinite
Red Sylvinite
Clay interbeds in rock salt

FIGURE 4-59 LOCATION & STRATIGRAPHY OF UPPER KAMA BASIN AND POTASH MINES

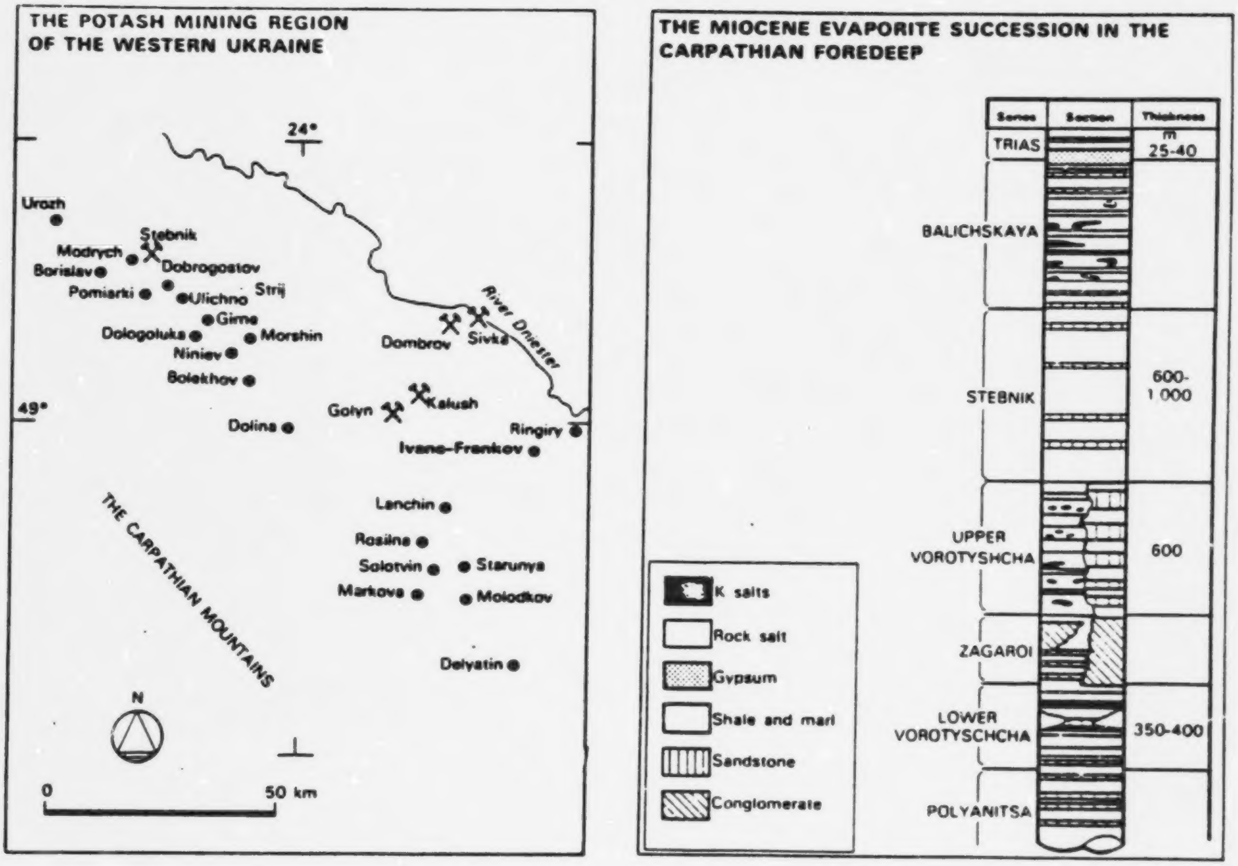
normally up to eight metres thick and four sylvinite seams are present, interbedded with halite layers three to six metres thick.

Lower and Middle Miocene (Fig. 4-60)

The western Ukraine is an area of significant importance for potash production in the U.S.S.R. Potash deposits are included as sediments deposited in a long narrow Miocene basin. The axis of the basin is orientated in a south southeast - north northwest direction. It is bordered to the southwest by the Carpathians and to the northeast by the main Russian platform. The open sea was to the southeast and four cycles of saline deposition are present each of which is separated from the other by clay, marl, siltstone, and sandstone accumulations as much as 1000 metres thick. Potash occurs in the first three cycles within the Lower Vorotyshcha Series although the principal commercial potash deposits occur in the second and third cycles.

The potash-bearing series is overlain by approximately 600 metres of clays, siltstones, and sandstones with interbeds of clayey salt and local lenses of potash. All are assigned to the Upper Vorotyshcha Series. Strata of similar lithologoies belonging to the Balichkaya Series are above these beds.

In the Kalush sector of the basin to the southeast sylvinite lenses are more abundant and better developed. It is inferred that a near-shore environment is indicated by these deposits. The sylvinite can be subdivided into upper, middle, and lower units. Important lenses of kainite ore occur in halite interbeds between the upper and middle beds. The upper unit commonly has interbeds of kainite and thin members of carnallite.



THE POTASH MINING REGION OF THE WESTERN UKRAINE

THE MIOCENE EVAPORITE SUCCESSION IN THE CARPATHIAN FOREDEEP

24°
49°
Urozh
Stebnik
Modrych
Borislav
Dobrogostov
Pomiarki
Ulichno
Strij
Girne
Dologoluka
Morshin
Niniev
Bolekhov
Dolina
River Dniester
Dombrov
Sivka
Golyn
Kalush
Ringiry
Ivano-Frankov
THE CARPATHIAN MOUNTAINS
Lanchin
Rosilna
Solotvin
Starunya
Markova
Molodkov
Delyatin
N
0
50 km
Series
Section
Thickness
m
TRIAS
25-40
BALICHSKAYA
STEBNIK
600-
1 000
UPPER
VOROTYSHCHA
600
ZAGAROI
LOWER
VOROTYSCHCHA
350-400
POLYANITSA
K salts
Rock salt
Gypsum
Shale and marl
Sandstone
Conglomerate

FIGURE 4-60 LOCATION & STRATIGRAPHY OF UKRAINE POTASH DEPOSITS AND MINES

4102 MINING METHODS

Soviet potash production, which accounts for over 25% of world production, comes from three large basins, the pre-Carpathian deposit in western Ukraine, the Starboin deposit in Byelorussia and the Upper Kama Basin near the Urals. The latter two are by far the most important, as they account for more than 90% of Russian production.

The geological conditions in the three basins are quite dissimilar (Table 4-6). In the Urals, the thick flat sylvinite seams have slight gradients, and some faulting evidenced by local folds. The producing seam is overlain by a rock salt seam which is normally thick enough to protect the mining areas from the brines and water present in the aquifers above the rock salt. In Byelorussia, there are two mineable sylvinite seams, which again are almost flat. The potash bed occurs beneath massive impermeable rocks of alternating clay and marl, which will lower without fissuring. In the Ukraine, where the potash is mined as a sulphide ore, the seams are thick, steeply dipping, with tectonic folding, faulting and considerable variation in seam thickness. Table 4-7 lists the mines and several locations.

.1 Mining Methods - Ukraine

The thick sulphide ores (10-15 m) are very hard and are not amenable to cutting by continuous miners. Mining in the steep deposits is by the shrinkage stoping method with sub-level access and with back-filling of the rooms between sub-levels using hydraulically transported fill. In the flatter deposits, a form of room and pillar mining with shrinkage stoping in the rooms is practised. These two methods are briefly described below.

The mining method depends on the dip of a deposit. Fig. 4-61 outlines the method employed in working a gently inclined thick bed of

TABLE 4-6

Mine	Potash Zone	Depth in Metres	Ore Type	Mining thick in metres	K_2O (%)	Insols. %
		LOWER AND MIDDLE MIOCENE - Western Ukraine				
UKRAINE REGION						
Stebnik (Novaya)	-	100-300	langbeinite, kainite, mixed langbeinite-kainite	1 - 5 18 max.	8 - 12	-
Kalush, (5 mines): Kainitovoya North (Severnoye) Kalush	-	100-300	sylvite, carnallite, kainite, langbeinite, schoenite, and polyhalite	-	9 - 12	9 - 14 lang. - kainite 18 - 33 sylvinite
Golyn: 50 Years to October, East Golyn	-	100-300	as above	-	as above	as above
Dombrov (OPEN CAST)	half lense	-	langbeinite, kainite, mixed langbeinite-kainite	7 - 101	10	-

TABLE 4-6

GEOLOGICAL CHARACTERISTICS OF USSR POTASH MINES

Mine	Potash Zone	Depth (m)	Ore Type	Mining thick (m)	K_2O (%)	Insols. (%)
			UPPER DEVONIAN - Soligorsk, Byelorussia			
Byelruskali Combine						
Soligorsk 1, 2, 3, 4	Layer II	350-620	sylvinite, halite interbed	1.8-4.4 (2.7 av)	17	5
	Layer II	160 below II	sylvinite	1.5-2.8	13.4-16.4	9
			PERMIAN - Upper Kama Basin; Berezniki, R.S.F.S.R.			
Uralkali Combine						
Berezniki 2, 3, 4 (and Novosolikamsk)	Red II	300-526	sylvinite	4.84 (combined)	21.1	0.5-3.0 (general area)
	A-B					
Solikamsk	Red II	250	sylvinite	4.74 (combined)	14.73	-
	A-B					

TABLE 4-7

Russian Potash Mines

Mine	Year	K_2O Mt/yr
Ukraine		
- Lvov	?	
- Novaya	1972	
- Novo Stepnik	1965	
- Stepnik	1946	0.4
- Kalush	?	
- Dombrov (open pit)	1966	
- Golyn	1967	
- Sivka	?	
Byelorussia - Byeloruskali		
- Soligorsk #1	1963/64	0.58
- Soligorsk #2	1965/67	0.65
- Soligorsk #3	1969/70	1.00
- Soligorsk #4	1980	1.45
Urals - Uralkali		
- Berezniki #1	1955	?
- Berezniki #2	1969	1.46
- Berezniki #3	1973	1.50
- Berezniki #4	1984	2.9
- Solikamsk #1	1933	?
- Solikamsk #2	1974	1.0
- Novosolikamsk	1984	2.9

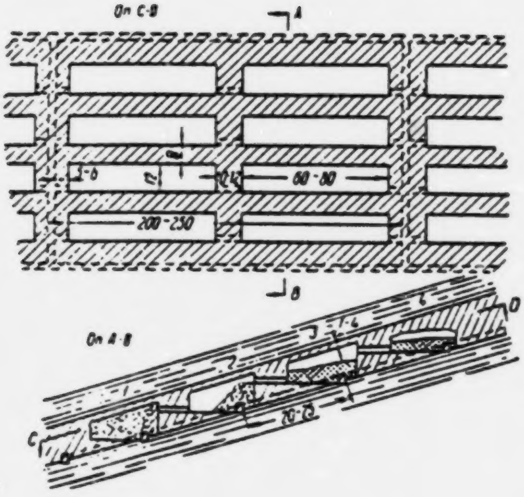

On C-B
A
5-6
12
12-14
60-80
200-250
B
On A-B
D
6
3
1-6
1
2
20-22
C

FIGURE 4-61 SHRINKAGE STOPING WITH BACKFILL
-GENTLY DIPPING DEPOSIT
-UKRAINE-U.S.S.R.

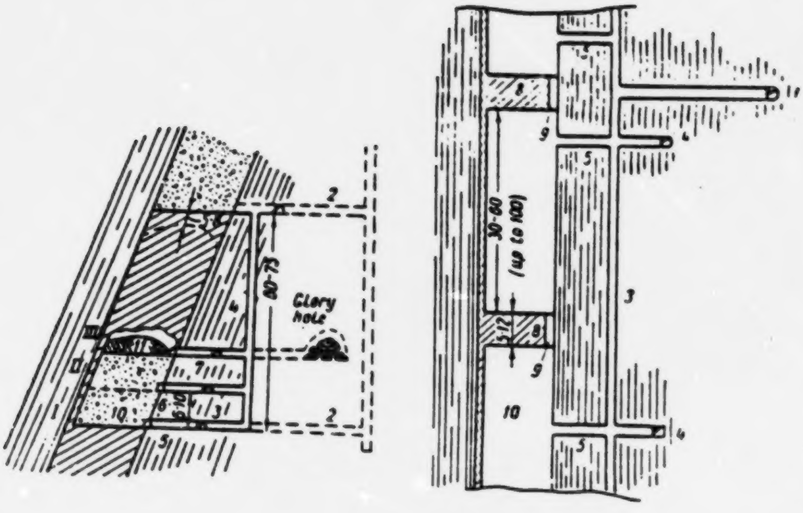

2
4
60-75
Glory hole
7
6
8-10
3
10
2
5
8
11
9
4
5
30-60
(up to 100)
3
5-12
8
9
10
4
5

FIGURE 4-62 POTASH MINING IN A STEEPLY DIPPING DEPOSIT SUB-LEVEL SHRINKAGE STOPING WITH BACKFILL UKRAINE POTASH MINES - U.S.S.R.

potash salt. The development of a panel provides for sub-levels on strike every 200 metres. Protective pillars five to six metres thick are left on both sides of the sub-levels. These pillars are cut through by entries run from the sub-levels every 20-25 metres. Outside the pillar such an entry is enlarged to the full width of the room (approximately 12 metres), with the height remaining at about two metres. This heading is run over the entire length of the room (around 60-80 metres), and after that the room is mined by the shrinkage method. As may be seen from Fig. 4-61, the floor of each room is flush with the level of the corresponding sub-level.

If a deposit is capped not by rock salt, but by anhydrite or saline clay, that is, by friable and easily caved rocks, a protective mineral barrier one to four metres thick is left in the roof of the room, as indicated in the figure. The cross-section of each room then has a characteristically trapezoidal shape. Between adjacent rooms on strike are support pillars which are later abandoned and, in addition to these, pillars 10-12 metres wide are left mid-way between two entries. Triangulary prisms of salt are also lost under each room.

The rooms are mined in the ascending order. When the potash has been removed from the rooms, they are filled. The fill material is brought down along the slope, first to the upper adjacent room, thence through a special inclined heading in the pillar to the room requiring filling.

The fill is put in place at as high a density as possible and for that reason special stowing machines are sometimes used to fill up to the roof. Fig. 4-61 shows room 1 already filled, room 2 in the stage of being filled, room 3 - broken potash is being hauled away, room 4 is in the mining stage of shrinkage-stoping.

Room mining in a steep bed is illustrated by Fig. 4-62. From shaft 1, sunk in the footwall of the deposit, crosscuts 2 are driven towards the potash bed. The main level interval varies from 30 to 75 metres. The levels are divided into sublevels I, II, III..., with vertical intervals of six to ten metres. The sublevels are developed by short crosscuts 5, 6, 7..., driven consecutively from blind shafts 4, raised to the entire height of the level. The sublevels are worked in ascending order. The operations progress in the following sequence. Level Drift 3 is run from main haulage crosscut 2 in the rock salt of the foot wall, from which short crosscuts 5 are driven to the site of future stopes. The crosscut is driven as a development opening about two metres high, extending all the way through the lateral thickness of the deposit (except for the protective barrier of potash salt one to four metres thick sometimes left in the roof) and the full plan area of the stope is then excavated at this level. Potash is then mined by the shrinkage-stoping. The ultimate height of the room corresponds to the sublevel interval, that is, seven to nine metres.

Insofar as the other dimensions of the room are concerned, they depend on the thickness of the working deposit, the strength of salt and the firmness of wall rocks. Normally, the overall area of a room should not exceed 600-1000 sq m with the more cavable and less viscid salts, but in more favourable conditions it can be increased to 1500 sq m.

Support pillars 8, measuring 12-15 metres, are left between rooms, except when on strike (six to eight metres). Cross headings 9 are cut near the foot wall of a deposit to connect neighbouring stopes. Interstope pillars in individual sublevels are immediately one over the other throughout the whole of the level interval. Sometimes reinforced (oversize) pillars up to 25 metres in length on strike are left every few rooms, for additional stability.

When the potash stored in shrinkage stopes has been loaded out, the rooms are stowed with filling material. The latter, brought down from the surface or obtained underground, is delivered to the top level of a given room. Thus, for room 10 the fill is supplied via intermediary crosscut 6.

Rock salt, mined in glory holes, (special chambers worked exclusively for mine-fill), is sometimes used as a backfill material. This is illustrated in Fig. 4-62 (on the right side of the vertical section). It may be seen that the glory holes lie at the footwall of a deposit, on a horizon overlying the sublevel room which is being filled. The interval between individual glory holes on the same sublevel is about 150 metres, while in adjacent sublevels along the dip they should not lie one over the other. The glory holes must not exceed 100 metres in length, 25 metres in width and nine metres in height to maintain stability.

The room to be filled is stowed so as to leave a free space about two metres high between its roof and the top of the fill. This space is for the drillers engaged in breaking the potash in the next sub-level stope (room II in Fig. 4-62). The extraction of the overlying sublevels proceeds in similar manner, but the potash is passed down to the main haulageway through intermediary levels and raises. At the top of the stope, a pillar five to eight metres high is left to serve as a safety pillar. The delivery of mined potash from the rooms and its loading into mine cars is usually done by a conveyor. The main haulage road is on strike and is serviced by electric haulage.

.2 Mining Methods - Byelorussia - Soligorsk Mines

The evaporite deposits of the Pripyat depression are of Devonian age and attain a thickness of over 600 metres in the Soligorsk area. Four major potash beds are present, the middle two only being mined at present:

		Thickness (m)	Grade (% KCl)	Insols (%)
20-50 m	Salt & clay			
	Seam 1	?	23	13
60-90 m	Salt & clay			
	Seam 2	2.7	28	5
150-200 m	Salt & clay			
	Seam 3	21.0	26	9
40-60 m	Salt & clay			
	Seam 4	?	20	12

Layers 2 and 3 are composite beds of sylvite and halite (rarely carnallitic) separated by clay beds of varying thickness. The sylvinite layers contain up to 50% KCl so that where only two layers are mined by longwall shearers a mined grade exceeding 30% KCl can be achieved.

The beds are relatively uniform between major fault blocks and are easily followed by the miners since the sylvite is bright red in colour. Locally disturbed areas are found, caused by solution and collapse of the overlying beds. Methane bearing gas is found throughout the deposit, associated mainly with the clay interbeds, but in the disturbed areas it has been concentrated in much higher quantities which provide a major hazard to mining.

The following succession overlies the evaporite deposits:

	Thickness (m)	Age
Sand, Gravel etc. with Clay beds	90 - 350	'Recent'
Chalk	20 - 25	Cretaceous
Marls & Shales	50 - 70	Jurassic
Dolomite, anhydrite and salt-clays	240 - 450	Devonian

The uppermost 200 - 350 m are heavily water-bearing.

At Soligorsk the potash seams and roof rock layers are characteristically thin and have a high clay content. The rock layers in the roof are often only five to 15 cm thick and are separated by numerous one to three centimetres thick clay layers. The stability of the layers is relatively poor. Therefore in retreating longwall mining the roof layers break up and cave immediately with great force and squeeze out mud into the roadways.

Mining Systems

Past Developments and Overview

Following the 1963 establishment of operations, the first mine used conventional room and pillar layout with strong pillars and drill and blast mining. The rooms were 10 m wide and the pillars between four and eight metres. Considerable danger of roof caving existed in these conventional mining systems. Scientific investigations showed that the failures of the thinly bedded roof strata were not due to their weight but were more so caused by the "punching effect" of the supporting pillars. Two ways were used to control the dangerous roof conditions:

a) A change to fully mechanized mining with tunnelling machines.

b) Attempts were made to control the "punching effect" of the pillar through empirical reductions of the width of the pillars; in this manner it was established that a favourable width of a chamber was 5.3 m and that of the pillar 1.2 m, resulting in a change from solid pillars to yielding pillars.

The present mining methods are listed in Table 4-8.

Table 4-8

Present Mining Procedures in the Soligorsk Mines in the Soligorsk Mines

Seam 2	Seam 3
(i) "Normal" R&P development (Fig. 4-63) with 3 rooms, 2 narrow between-room pillars and 1 wide supporting pillar after every 3rd room	(i) "Normal" R&P development (similar to Seam 2).
(ii) Room & Pillar development with yielding pillars. (Fig. 4-64)	(ii) Combination Mining (Fig. 4-66) - top cut with longwall - bottom cut with "normal" R&P development.
(iii) Single lift longwall (with only 1 part of the seam mineable).	
(iv) Two-Lift longwall. (Fig. 4-65)	

"Normal" room and pillar (Fig. 4-63) uses wider supporting pillars to prevent the lowering of the roof, as opposed to development with yielding pillars. Mining machines of the SchBM2 and 3, PK 8, PK 10 and Ural 10 KS full face borers type are used. Longwall is carried out with shearer loaders.

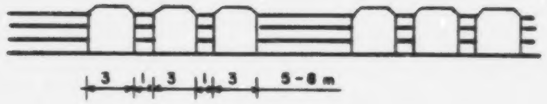


FIGURE 4-63 CONVENTIONAL LONG ROOM & PILLAR (NON-YIELDING)

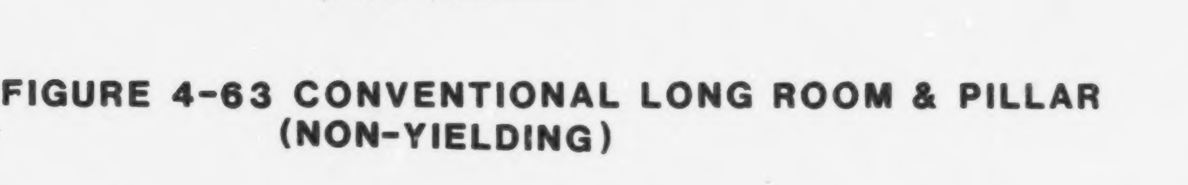


FIGURE 4-64 LONG ROOM & PILLAR WITH YIELDING PILLARS

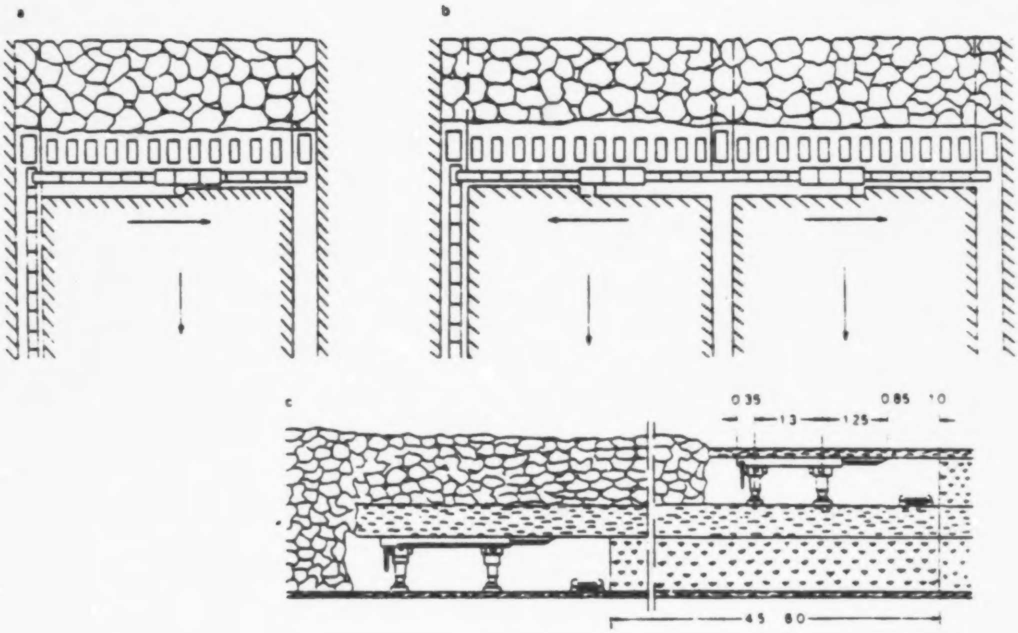

a
b
c
0 35
0 85
1 0
1 3
1 25
45 80

FIGURE 4-65

LONGWALL MINING (CAVING) IN TWO LIFTS
ON SINGLE OR DOUBLE FACES

POTASH MINES IN BYELORUSSIA - USSR

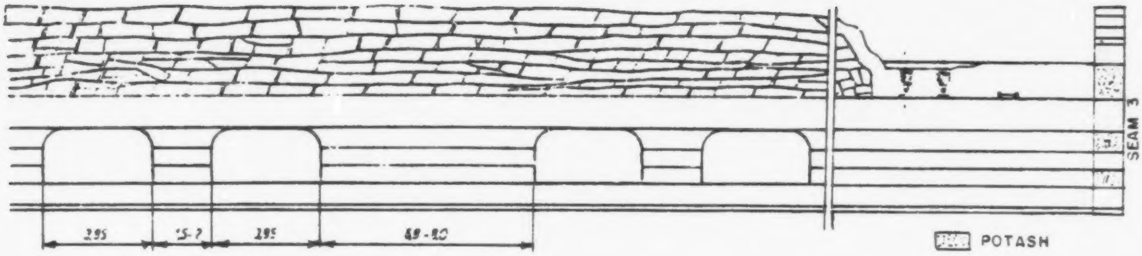

295
295
SEAM 3
POTASH

FIGURE 4-66 COMBINATION MINING
- TOP LIFT LONGWALL CAVING
- BOTTOM LIFT ROOM & PILLAR

Long Room & Pillar with Yielding Pillars

The mining panel is prepared by driving four entries with PK 10 (5.3 m width) or with Ural 10 KS (3.85 m width) machines. Pillars three metres wide and seven to eight metres long are left between the entries.

The mining rooms are driven in a similar manner at right angles to the main entries to a length of 200 m. Pillars of 1.20 m ± 0.03 m width are left between the rooms (Fig. 4-64). With the advance of the mining face these pillars yield and are crushed so that the roof can be lowered unbroken to the floor.

One machine operates in each panel (three to four days per room). The ore produced by the mining machines is loaded via a mobile bunker into a shuttle car and then transferred to a panel coveyor and then to the main belt conveyor. The output varies between 1200 and 1800 t/day due to problems which arise with the transportation system.

Two-level longwall with Shearer

The 70 to 100 m long longwall face is developed through two to three parallel development roadways that are driven by the PK 8 (the roadway width is three metres and the width of the pillars three metres). Mining is done in two level retreating longwall (Fig. 4-65), with the upper level cutting first.

The mining is done by a vertical drum shearer loader (MK 97 type) that moves on a flanged chain conveyor of 0.80 m width. The shearing width is 0.65 m. The shear height is adjusted to the mineable height of seam interval and can be varied between 0.90 m and 1.14 m with the aid of segments added to the vertical drum of the shearer. The broken ore is transported off the face by chain conveyor, and delivered onto a stage loader or telescopic chain conveyor in the gate that transports it 50 to 200 m to a belt conveyor. The longwall face is supported with self-advancing chocks - always in pairs with two double telescoping legs with rated holding capacity of 40 Mp. The props have round floor plates, and the supports are advanced sequentially into the newly exposed cut. The legs are retracted upwards, and the chock supported by its paired chock, on slide bars. This differs from other mining practices, however, the use of round slide bars works well in the limited longwall height. The minimum height of the chock is 0.70 m and the maximum is 1.15 m.

The second level face is mined 4.5 to 6.0 m away from the first using the same type of equipment. Immediately following both the first as well as the second faces the roof breaks directly behind the chocks. (Fig. 4-65)

The roof of the roadway alongside the face is supported by 5 to 7 single leg hydraulic props with wooden caps. The distance between the props is 1.3 m.

Each day the longwall face advances four to five metres which corresponds to an output of 250 t of ore per shift.

Combination Mining in Thick Seams

In the up to six metres thick Seam 3 mining is locally different, and some seam horizons are only mined where safe. If the total removal of Seam 3 appears too risky because there is no guarantee that the watertight horizon will bend without breaking, then the combination mining method is used (compare Fig. 4-66). A mineral rich upper slice is mined with longwall, whereas the lower slices are mined with conventional room and pillar with no caving (using mining machines PK 8 or Ural 10 KS).

.3 Geotechnical Problems - Byelorussia

Geotechnical investigations into mining methods covering depositional conditions, hydrology, mining technology and operations are used to plan and oversee the mining process so as to ensure the safety of people and the deposit while striving to maximize efficiency of recovery. Solving of the geotechnical problems at the Soligorsk potash mine is in the hands of the Leningrad Institute of Halurgy (WNHG). It is concerned with the following:

a) Finding the reason for the roof failures with the originally sized supporting pillars.

b) Developing and testing new mining methods and techniques that will improve the safety of the mining crews and substantially increase recovery.

The "piercing effect" of the supporting pillars in "normal" room and pillar mining was recognized as the reason for roof failures, and the following countermeasures were applied:

- changes in mining technology, i.e. changing from drill and blast to cutting with continuous mining machines.

- gradual decrease of the width of the pillars, i.e. changing from room and pillar with supporting pillars to room and pillar with yielding pillars.

- introduction of longwall mining in areas with limited mineable heights.

During the changeover to the above mining methods, recovery was increased from 40%-50% to 75%-90%, and the development of basic principles, planning and application required the solution of several geotechnical problems.

a) Finding the necessary thickness of safe saltback for the mining of Seams 2 and 3;

b) Mining direction;

c) Optimum size of rooms and pillars in room and pillar mining with yielding pillars;

d) The safety (resistance to collapse) of roadways and crosscuts; and

e) Clarification of the deformation and failure behaviour of unsupported roof, including the caving area over longwall.

Geotechnical Investigations and Results

Thickness of Safety Layers

Considering the geological conditions of the deposit, it remained to be determined whether, with the improved mining methods - longwall and room and pillar with yielding pillars - the presence of the 200 to 300 m thick safety horizon would be sufficient to prevent water influx. For this reason physical modelling experiments with equivalent materials were done, and later trial mining with geotechnical control was done.

The experimental mining model consisted of a simulated longwall in Seam 2 (approximately two metres thick) and of a simulated room and pillar with yielding pillars in Seam 3 (approximately 4.5 m thick). Liquid was placed above the simulated saltback safety layer. From the model, fissures only developed in the first 130 metres of salt back, whereas in the mine there actually is a 200 to 300 m thick safety layer. WNHG determined that in order to mine Seam 2 by caving longwall, the safety layer must exceed the mined thickness of the seam by a factor of 40. Subsequent experiments suggested that this factor can be significantly smaller. The final conclusion however must await the outcome of the full range of tests currently being undertaken. The controlled lowering of the roof in room and pillar mining with yielding pillars requires substantially less of a safety layer than is required in caving longwall mining.

Controlled geotechnical measurements were and still are being made to observe the length and width of the caved and bending zones in the lowering of the roof in longwall mining (Seam 2). These include:

a) Permeability tests with pneumatic packers indicated caved zones about eight to 10 m thick (approximately four to five times the seam thickness);

b) Geophysical measurements (seismic, electric) in drill holes in the roof above mined areas to determine the fracturing of the overburden under the influence of a passing longwall machine;

c) extensometer measurements, partially with optical drill hole observation devices inserted in 80 to 100 m long box holes in the roof.

Figure 4-67, illustrates, the results obtained from the various testing methods and shows that the caved zone extends only to a height approximately eight metres (corresponds to a ratio of 1:4, seam thickness to roof thickness). Above this zone bending of the strata occurs with an upward decrease in magnitude.

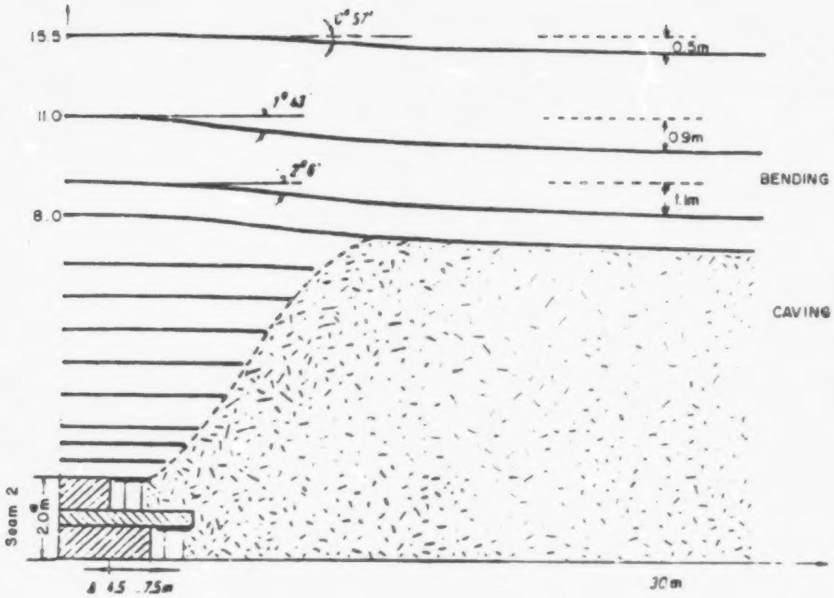

15.5
0°57'
0.5m
11.0
1°43'
0.9m
2°6'
BENDING
1.1m
8.0
CAVING
Seam 2
2.0m
4.5
7.5m
30m

FIGURE 4-67 DEVELOPMENT OF BREAK AND RIP OF THE ROOF OF SEAM 2 BY USING A TWO STEP METHOD LONGWALL

Convergence measurements above and below the faces prove the efficiency of the proposed mining methods. For example, the rate of lift in the floor in longwall mining (4.5 mm/day) is only approximately double the rate in room and pillar with yielding pillars (2.5 mm/day).

The tests have shown that under the present practical conditions (400 m maximum width, 400 to 500 m depth) both longwall face lifts can be well controlled geotechnically and hydrologically.

.4 Mining Methods - Uralkali - Berezniki and Solikamsk Mines

The deposits at Upper Kama have been defined through complex development and exploration. The extensive seams AB and Red II cover 90% of the area and are 1.8 to 4.2 m and two to six metres thick respectively and these wide variations appear to be uniformly distributed with changes from two to three metres occuring over distances of 15 to 20 m. The hanging wall has weak rock up to 1.2 m thick that requires special measures in mine development. Both seams are weakly undulating over distances of five to 20 m and the folds have amplitudes between 0.5 and 4 m. Downdip and along the strike the floor of the underground workings dip 15° and 5° to 10°, respectively. The mining of the seams is made difficult because of thin impermeable strata and gaseous occurences from rock and gas bursts.

In the Upper Kama deposit, room and pillar with continuous miners (80% extraction) and drill and blast methods is used exclusively. The reasons are the presence of considerable aquifers and minimal thickness of impermeable strata. As a rule a panel is 400 m wide and up to 3 km long. A mine panel is developed between two ventilation roadways and divided into two half panels through a central panel entry (Figure 4-68a). The rooms are developed towards the ventilation entries and are cut by continuous miners in single slices from top towards the bottom. The number of slices (one to four) depend on the seam thickness and the type of machine. The number of cuts per slice is dependent on the stoping method and normally do not exceed four. The cuts are separated by 0.7 m wide pillars to support the roof (Section BB).

The cuts in the upper slice are auxilliary ventilated and the other cuts by through ventilation. The potash salts are loaded onto the mine panel conveyors through 370 mm to 750 mm diameter holes drilled from the panels to the lower salt beds (Section AA). Under weak roof conditions all cuts are made separately and are removed through a common drift to avoid creating large openings (Figure 4-68b), the panel entries being formed by three separate roadways. The central one is used for ore removal and the two outer roadways serve for the transportation of equipment and material during the mining of the respective half panel. To prevent sudden rock and gas bursts, drainage holes are drilled one metre to 1.5 m apart. When necessary, the roof is secured with anchors or expansion-shell bolts on a 1.5 x 1.5 m pattern. In order to improve mining techniques, attempts are being made in seams up to five metres thick with a competent roof to use yielding support pillars, which increases the extraction rate from 35-50% to 60-65%. The future development of this method depends on the present detailed investigations of the behaviour of the saline rocks and the prevention of water inflow.

The mining machinery consists of a continuous miner, a shuttle car and feeder breaker. All continuous miners (PK-8M, Ural 20-ks and Ural 10-ks) are full face machines. The PK-8M miner with a rotary cutting head and with a capacity of 4.2 tonnes per minute is primarily used in development work, the "Ural" miner with rotary cutting heads is used in mining and in development work within a mining panel. The "Ural 20-ksA" and "Ural 10-ksA" miners have a capacity of 5.0 and 4.0 tonnes per minute and installed capacity of 535 and 455 kw. The

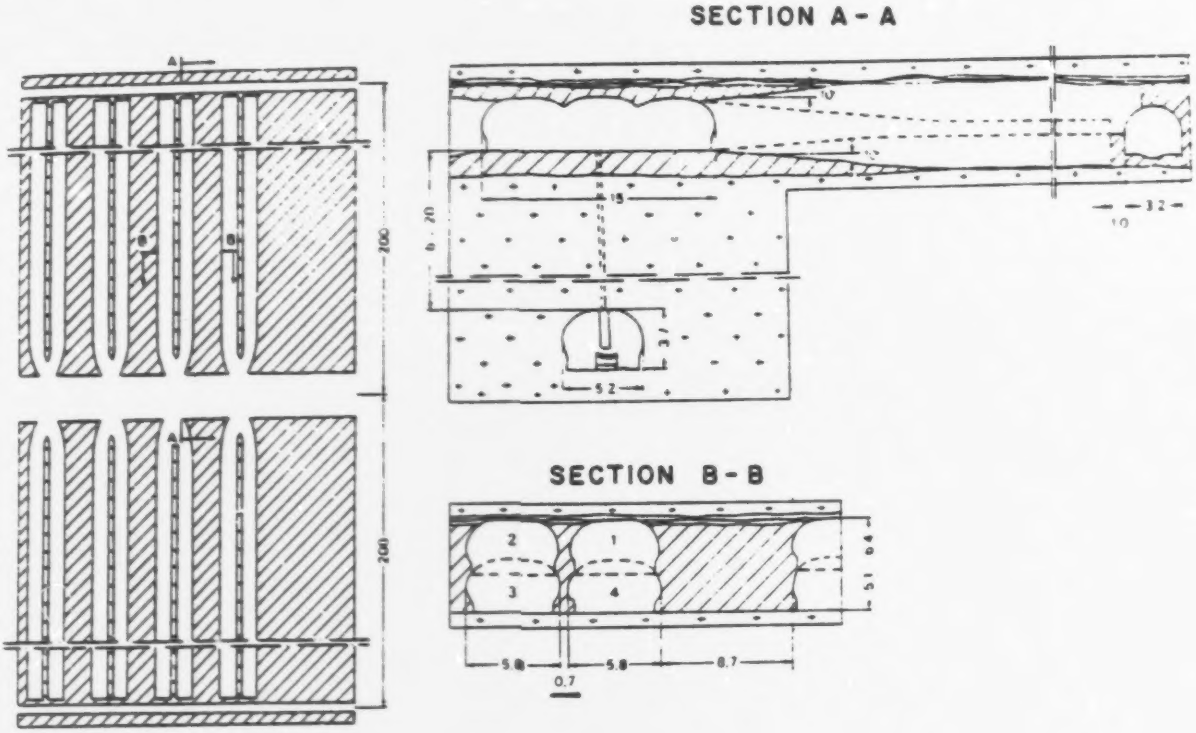
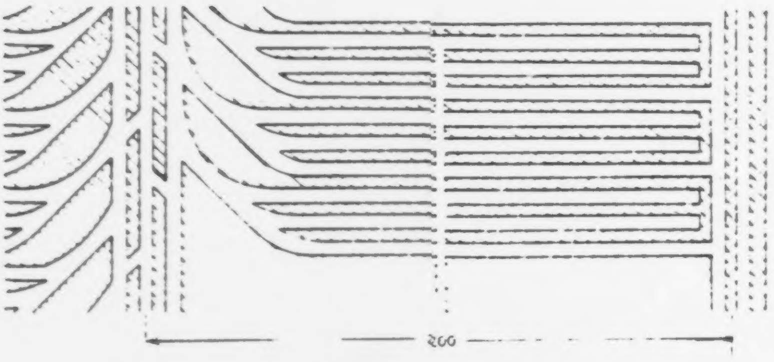

SECTION A - A
A
B
200
200
15
3.2
10
3.7
5.2
SECTION B - B
2
1
3
4
6.4
5.1
5.8
0.7
5.8
8.7

FIGURE 4-68
LONG ROOM AND PILLAR MINING IN URALKALI MINES USSR USING BORER MINERS
(a) ABOVE IN GOOD ROOF CONDITIONS
(b) BELOW IN POOR ROOF CONDITIONS



cutting cross-sections measures 13.1 to 20.2 m^2 and 7.8 to 10.2 m^2 respectively.

The 5BC-15M shuttle car transports the ore from the miner to chain feeder conveyors and belt conveyors; the hauling distance normally does not exceed 200 m. The shuttle car is powered by an explosion-proof AC electric motor with a capacity of 127 kw (660 V) with three speeds. A distinguishing characteristic of the shuttle car is that the load box can be tipped and therefore the emptying cycle of shuttle car can be 1.5 to 1.7 times shorter when compared to a conventional shuttle car.

The mobile bunker BP-3A receives the ore from the miner. Its storage capacity is sufficient to fill a shuttle car and provides for accelerated filling of the shuttle car. The bunker has automatic controls for loading and unloading. When operating, it is pulled along by the continuous miner and requires no human attention.

By using a mobile bunker instead of a second shuttle car it is not necessary to pick up the ore from the floor a second time. Therefore the capital and operating costs are considerably reduced and a smaller mining crew is possible consisting of a miner operator and a shuttle car driver. Such an arrangement of equipment results in a production capacity of 32 000 t/month for the PK-8M miner, and 58 000 t/month for the Ural 20-ksA and Ural 10-ksA miners.

The mining technique using drilling and blasting with square pillars (Figure 4-69), permits an increase in the extraction from 48% to 60%. Its main distinguishing characteristic is the development of mine working along the axis of the mining room. This protects the ventilation entries during drilling and blasting and achieves better efficiency through the use of development roadways as entries. To avoid the filling up of the development roadways and the disruption of ventilation the rooms are developed in two slices with the lower one being developed first. The breakthrough between mining rooms is accomplished from opposing sides, with drill holes of 450 mm diameter serving as initial break throughs. Ventilation results with this partial air access. The roof is secured with roof bolts. In areas with intensive folding that prevents the use of self-propelled equipment, the recovery is accomplished through small boreholes with portable drill and conveying equipment, and the use of scraper loading equipment.

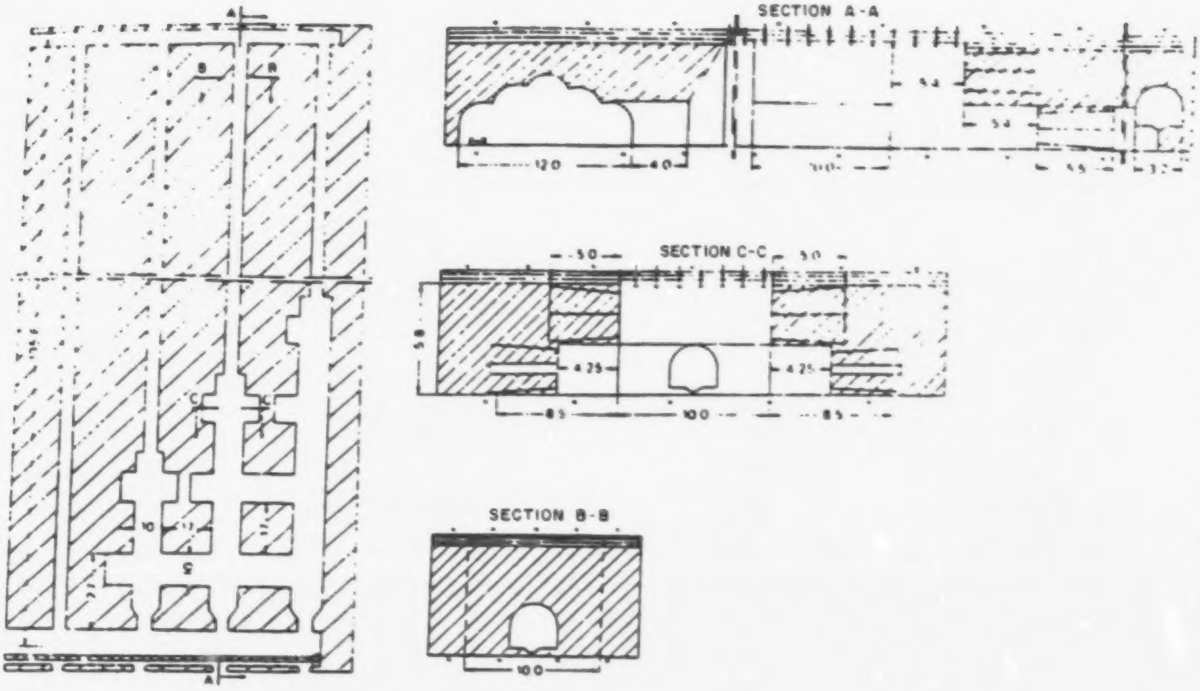

A
B
B
C
C
A
SECTION A-A
120
40
5.4
5.4
5.5
SECTION C-C
5.0
5.0
5.8
4.25
4.25
8.5
10.0
8.5
SECTION B-B
10.0

FIGURE 4-69 CONVENTIONAL ROOM & PILLAR MINING (NON-YIELDING PILLARS) IN THICK SEAMS

4.11 ELSEWHERE

4111 CONGO

GEOLOGICAL ASPECTS

Commercial exploitation of potash deposits in the Congo was terminated in 1977 at the one producing mine in the area following a disastrous flooding of the operations by waters from an aquifer overlying the deposit. Nevertneless, the particulars of the occurrence and knowledge of conditions at the Holle Mine are considered to be useful for comparative purposes.

The Lower Cretaceous evaporites of the Congo Basin are also of considerable interest because of the close relationship with the Seripe deposits of Brazil. The two deposits are regarded to have a common areal origin prior to separation of the two continental masses.

Evaporite deposits of West Africa occur between Gabon in the north and Angola to the south. Subbasins have been identified with differing details of depositional patterns within each. The Congo Basin is bounded to the east by horsts and pre-Cretaceous crystalline massifs. Structural highs off the coast on the edge of the continental shelf are the limiting extent of deposits to the west (Fig. 4-70).

Three major Cretaceous lithologic units have been delineated. The lower part is comprised of continental clastic sediments deposited on a highly irregular erosional surface of the Precambrian basement rocks. Evaporitic rocks bearing potash beds constitute the middle succession. These strata are normally about 1000 m in thickness. The uppermost unit includes marine and littoral sediments.

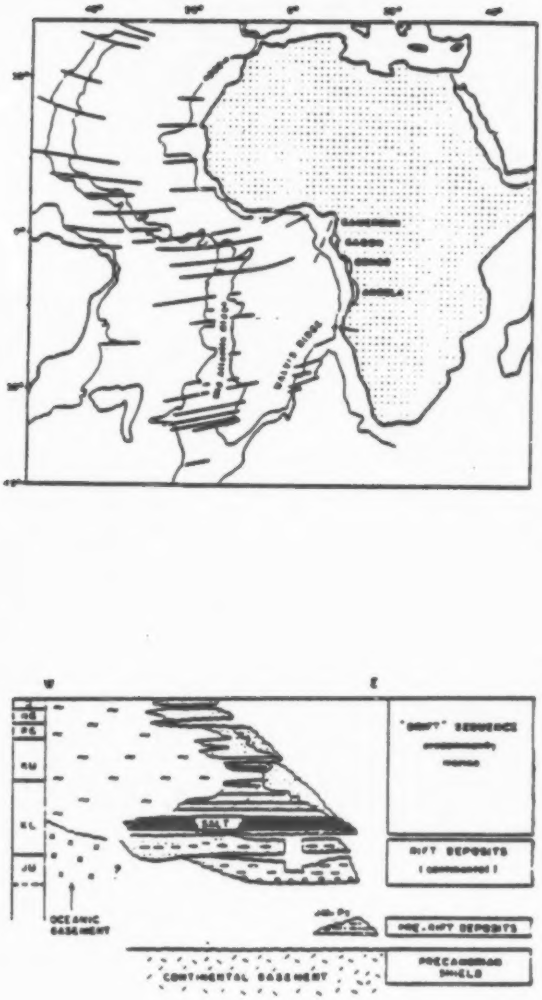

CAMEROON
GABON
CONGO
ANGOLA
WALVIS RIDGE
W
E
NG
PG
KU
KL
JU
SALT
"DRIFT" SEQUENCE
RIFT DEPOSITS
OCEANIC BASEMENT
PRE-RIFT DEPOSITS
CONTINENTAL BASEMENT
PRECAMBRIAN SHIELD

FIGURE 4-70 STRATIGRAPHY & LOCATION POTASH DEPOSITS - CONGO

The most favored potash zones for commercial interest are found in the Congo region. The evaporite unit demonstrates cyclical sedimentation patterns and each cycle includes a basal shale, overlying halite beds, with potash at the top. Each cycle varies between 60 and 150 m in thickness and 10 cycles have been identified. There are as many as 12 potash horizons in the area although the basal and uppermost beds are not always present.

Carnallite is the predominant potash mineral. Sylvite is also commonly present and is regarded to be of secondary origin. A few of the potash cycles contain bischofite and tachyhydrite. The carnallite beds are normally of regular thickness and show extensive lateral distribution. The accumulated thickness of these beds in the Congo is about 100 m.

The richest potash beds occur in beds 3, 7 and 8 of Cycle IX. In the Holle Mine, (Figure 4-71) bed 3 has scattered sylvinite pods and lenses throughout the carnallite-rich zone. One such lense is 2.7 m thick, contains 35 percent K_2O, and was mined at a depth of about 370 m. Such sylvinitic bodies are typically folded and of variable thickness. Beds 7 and 8 constituted the upper ore zone at 288 to 380 metres in depth. The beds are 1.8 m thick and grade 20 percent K_2O. Reserves at Holle are estimated to be 43 million tonnes K_2O equivalent.

Structurally, the evaporite beds dip regionally at low angles towards the west. At the eastern limits of the sediments they occur at depths between 200 and 250 m. Along the coast the beds are at 600 m in depth.

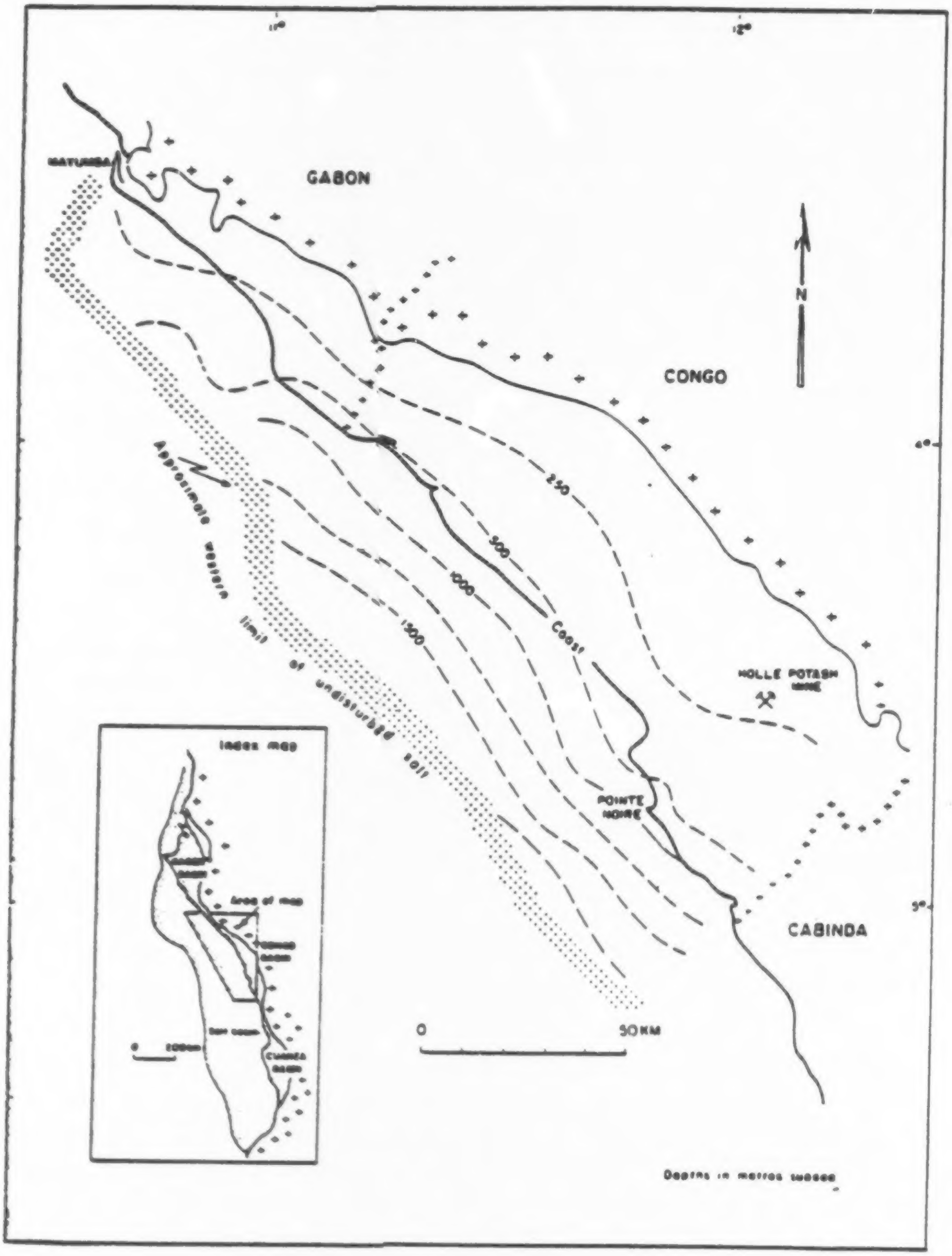

10°
12°
MAYUMBA
GABON
CONGO
N
4°
5°
250
500
1000
1500
Coast
Approximate western limit of undisturbed salt
HOLLE POTASH MINE
POINTE NOIRE
CABINDA
0
50 KM
Index map
Area of map
0
200km
Cuanza basin
Depths in metres subsea

FIGURE 4-71 TENATIVE ISOBATHS OF THE TOP SALT IN THE CONGO BASIN AND LOCATION OF POTASH MINE

MINING ASPECTS

Compagnie des Potasse du Congo (CPC) began producing potash at its St. Paul mine near Holle in the Congo in 1969 with a planned output of 500 000 t of K_2O.

The entrance of the mine was through a 5.5 m diameter shaft sunk to a depth of 420 m. The access to the potash was through three parallel roadways 1300 m long driven through rock salt. The mining was performed by a Marietta continuous miner supported by a conveyor. The mining system was room and pillar. The continuous miner created an initial opening 4.5 m wide by 2.6 m high, and loaded into 10 t shuttle cars. The original opening was then enlarged by a second operation in which a slot was cut by a chain cut at floor level. The face was then drilled and blasted and the ore removed by front-end loaders or gathering arms and shuttle cars. The enlarged rooms were 12 m wide by three metres high leaving pillars seven metres wide between rooms.

CPC could not achieve the planned production as it was discovered the sylvinite beds were severely folded with irregular thickness. This geological condition was similar to Texasgulf Inc.'s property in Utah, U.S. which abandoned conventional mining in favour of the present solution mining operation. CPC began mining carnallite which occurred as thick beds unaffected by folding.

Only 3.2 Mt KCl were produced from 1969 to 1977 when the mine flooded. There are plans to rehabilitate the mine under the 1982-86 development plan.

4112 BRAZIL

.1 Geological Aspects

Investigations to date have shown many similarities between the evaporite basins of Brazil and those of West Africa. Reconstruction of a common area of deposition prior to the splitting of the continents has provided additional understanding of the geological settings of both deposits. Along the eastern coastal region of Brazil, Lower Cretaceous clastics occur immediately above Precambrian rocks and achieve thicknesses of about 6 000 metres in the Sergipe Basin. The basement surface is of high relief thus resulting in highly variable thicknesses of the clastics. The overlying Muribeca Formation includes conglomerates, sandstones, reefal limestones, and evaporites which lap onto the Precambrian highs in places. The evaporites included in this unit have been assigned to the Ibura Member and are normally 450 m thick. The Ibura is comprised of several cyclical successions which vary greatly in thickness. Those cycles which are of greater thickness typically include, from base to top, beds of halite, carnallite, tachyhydrite, and sylvite. The upper part of the Member has some anhydrite strata.

The Brazilian evaporites are unusual because of the general absence of basal carbonates and sulfates. The presence of abundant tachyhydrite is also atypical. Two such zones, approximately in the middle of the Ibura Member, together total 100 m in thickness. Geochemical evidence suggests that brines that precipitated tachyhydrite were rich in calcium and depleted in sulfates. Convincing comparisons have been made between the deposition of potash salts in Brazil with those precipitated from the Red Sea during the Miocene through influences of geothermal brines activated by rift phenomena.

Evidence is available that tachyhydrite precipitated during total closure of the basin. It is further possible that the Sergipe region was situated towards the distal or north end of the depositional trough, in keeping with indications that the open sea lay to the south. This interpretation is largely based on studies of variations of geological conditions in West Africa.

Brazil's first production of potassium is scheduled to begin at Carmopolis, Sergipe (Figure 4-72) in 1984 by Petrobas Mineracao-Petromisa, the mining subsidiary of Petrobas at an initial rate of 100 000 t/a and to increase to 500 000 t/a.

The local geology of the aforementioned deposit is limited to a northeast fault and extends west about 40 km. The deposit is in a gruben resulting from structural deformation . Eight formation cycles are of soluble salts and two contain anhydrite, limestone and shale. Tachyhydrite underlies the sylvite layer. The sylvite layer to be mined by Petromisa lies 460 m below surface. The second layer lies four to 10 m deeper with halite between the two. The grade of the sylvite is estimated to be between 15%-21% K_2O and sylvite seams vary between three and 10 m thick.

.2 Mining Aspects

Mining at Carmopolis will be carried out through two vertical shafts each of five metre diameter: one 360 m deep for production and one 458 m deep for transportation of workers. The mining system will be long room and pillar.

Special protective measures will have to be undertaken to minimize water flowing into the mine workings. The potash reserves are near a producing oilfield and Petrobas is lining all oil wells with cement to prevent water and gas seepage from the wells into the mine workings.

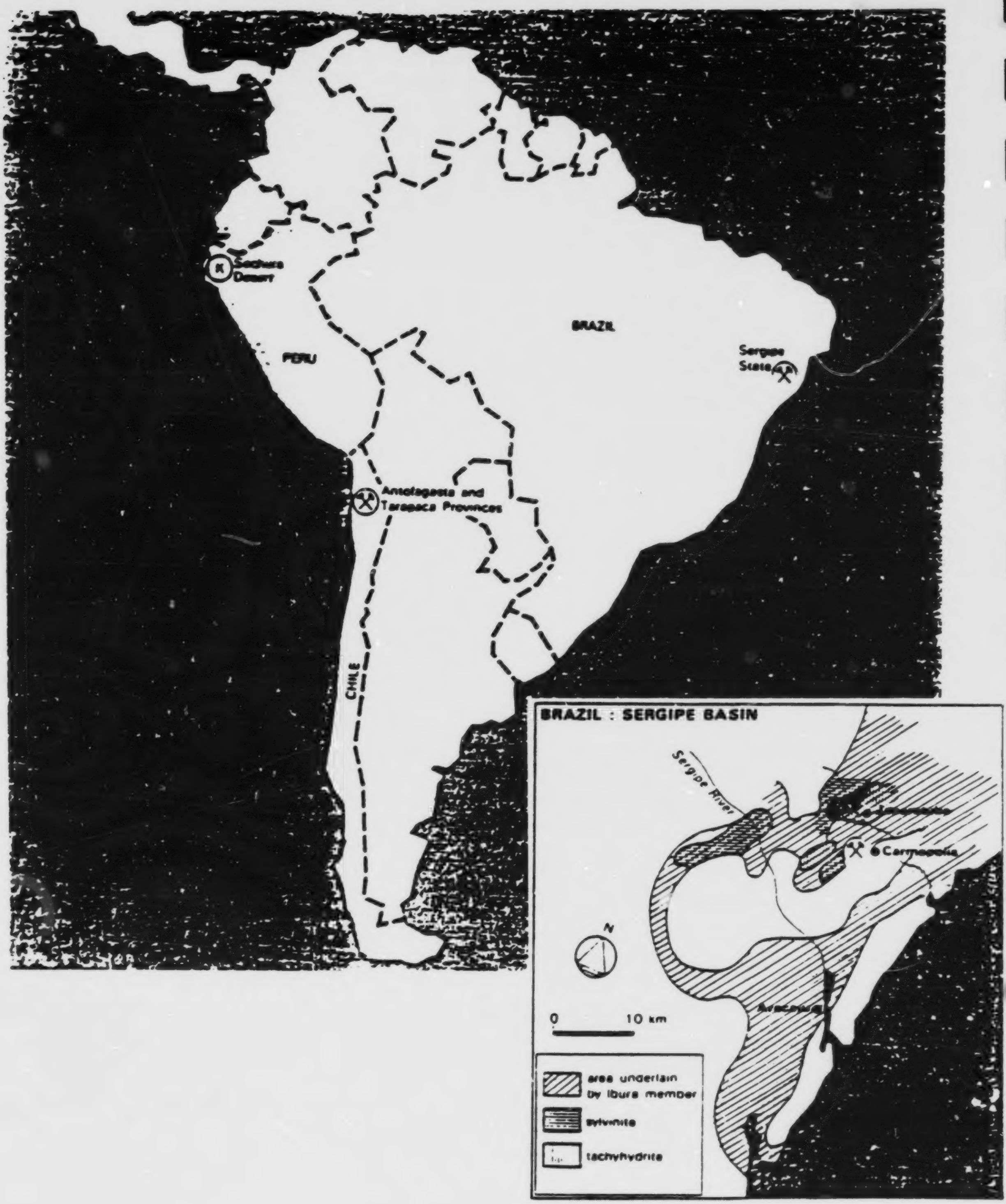

Sechura Desert
PERU
BRAZIL
Sergipe State
Antofagasta and Tarapaca Provinces
CHILE
BRAZIL : SERGIPE BASIN
Sergipe River
Carmopolis
Aracaju
N
0
10 km
area underlain by Ibura member
sylvinite
tachyhydrite

FIGURE 4-72 LOCATION & REGIONAL GEOLOGY POTASH DEPOSITS - BRAZIL

.3 Geotechnical Aspects

Rock mechanic analyses and tests have been carried out to assess the feasibility of mining underground long room and pillar mining in Sergipe, Brazil. The problem is how to mine the potassium without removing the pressure from an underlying body of tachyhydrite which absorbs water rapidly. Basically the problem is to determine the thickness of the layer to leave between sylvite and the tachyhydrite.

The analysis performed indicated that the closure rate in the rooms will increase due to tachyhydrite but that it is possible to mine the overlying potash. Analysis also showed that although potash and other evaporites exhibit strain hardening, room closure at approximately constant velocity is predicted when creep of the floor and roof are considered together with the creep of the pillar.

4113 THAILAND

.1 Geological Aspects

Drilling programs carried out by the Government of Thailand, Department of Mineral Resources in the Khorat and Sakon Nakhon basins have established the occurrence of potash minerals in the form of carnallite and, in lesser amounts, of sylvinite at depths of 90 to 500 m. Reconnaissance drilling of 63 boreholes spaced across 50 000 km^2 showed carnallite in more than half the holes. This indicates that the potash deposit may be one of the world's largest. The Khorat Plateau shown on Figure 4-73 contains potash in a salt-bearing sequence of Cretaceous age. The deposit consists mainly of carnallite with tachyhydrite and sylvinite also present. At several locations high grade sylvite bodies up to 34 m have been discovered. Indications are present that the sylvite has been formed by leaching of carnallite by some unknown solutions.

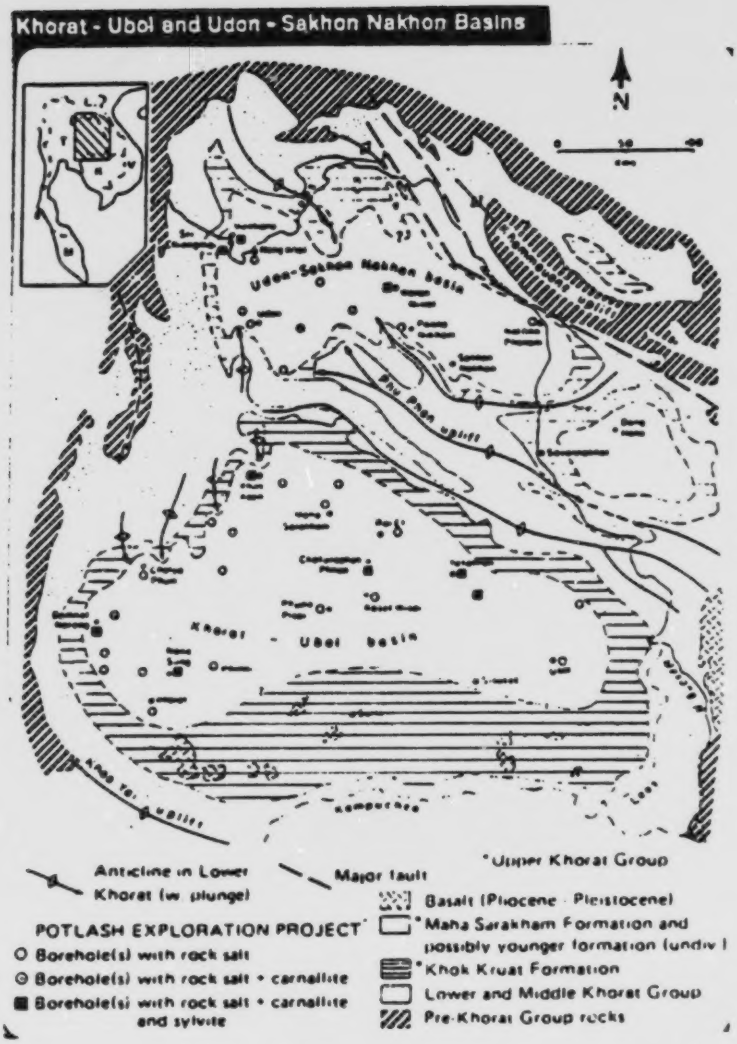

Khorat - Ubol and Udon - Sakhon Nakhon Basins
N
Udon-Sakhon Nakhon basin
Phu Phan uplift
Khorat - Ubol basin
Khao Yai uplift
Kampuchea
Laos
Anticline in Lower Khorat (w. plunge)
Major fault
*Upper Khorat Group
Basalt (Pliocene - Pleistocene)
*Maha Sarakham Formation and possibly younger formation (undiv.)
*Khok Kruat Formation
Lower and Middle Khorat Group
Pre-Khorat Group rocks
POTLASH EXPLORATION PROJECT
○ Borehole(s) with rock salt
◎ Borehole(s) with rock salt + carnallite
■ Borehole(s) with rock salt + carnallite and sylvite

FIGURE 4-73 REGIONAL GEOLOGY OF POTASH DEPOSITS THAILAND

The sylvite bodies are peripheral to barren halite and their size and structure are not defined as yet. Some of the sylvite has graded up to 24% K_2O.

High grade carnallite (13% to 14% K_2O) was identified at Bamnet Narong and Udon. Subsequent development drilling of 33 holes at Bamnet Narong has established the existence of a carnallite body that could justify mining.

A preliminary study has been undertaken of the Bamnet Narong potash deposit based on a mining reserve of 175 million tonnes of carnallite grading 13% K_2O.

.2 Mining Aspects

The mining method contemplated for Bamnet Narong deposit is a modified room and pillar system. The main access will be an incline at a grade of 16 percent. Two shafts would be sunk for ventilation. The main entry to panels would be by means of a five entry system with a conveyor located in the middle entry. The mining equipment would be continuous miners, loader-truck/shuttle car, feeder breaker and conveyor.

It is planned that thick seams may be mined either full face or in two passes, taking the upper seam first, but this will depend on seam thickness and choice of mining equipment.

.3 Geotechnical Aspects

An understanding of the mechanical properties of the rocks is essential for the successful exploitation of the potash. It is believed high extraction will be more difficult than other evaporite deposits at similar depth (around 170 m) due to the low strength of the carnallite and tachyhydrite and the relatively thick horizon. The areas of concern are:

- design of support pillars
- effect of humidity on rock strength
- subsidence of overlying rock
- water intrusion

4114 CHINA

There are three underground mines working in China but we have not been able to obtain any details of the geology or mining methods.

PART 5

MINING METHODS SUMMARY

PART 5 - MINING METHODS SUMMARY

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5.0 MINING METHODS SUMMARY

In the previous two sections, we have described the various methods used around the world to mine potash underground.

In order to summarize these methods, we must first define the various mining methods and conventions used in this report. These are given in Table 5-1.

In Table 5-2, we have listed, where known, the mining methods currently in use in each country and mine around the world.

Table 5-3 summarizes the production capacities and number of mines employing each mining method. It should be noted that these figures include mines using more than one method. It is interesting to note that approximately 65% of the mines use room and pillar methods to produce 70% of the world's output, and that over 21% of the remaining production comes from 22% of the mines using longwall caving, shortwall or open stoping systems.

One of the most important aspects of any mining method is the reserve recovery attained. We have not compared overall recoveries since these reflect the particular circumstances of each mine take. A more realistic comparison is obtained by looking at panel recoveries. These are given in Table 5-4.

It will be noted that room and pillar methods have much lower recoveries. The lower figures given for room and pillar reflect the Saskatchewan conditions, whilst the higher figures reflect the better roof conditions present in the USA and Europe. Of particular interest are the greatly increased recoveries being achieved by all the other methods

- longwall, shortwall, various forms of stoping and of course solution mining.

It is also noticeable that the mines now using the longwall and shortwall methods all started out with conventional room and pillar mining. However, due partly to poor recoveries, partly to strata control problems, and partly to improvements in mining machinery, roof supports and rock mechanics capabilities, all the mines have in the last 10 years converted to longwall and shortwall systems for the benefit gained in improved recovery, better strata control and better working conditions, and presumably lower costs, since the new methods are still in use.

In many cases, introduction of these methods was preceded by extensive geotechnical test programs, modelling experiments, underground observations and mining trials. As a result of these efforts, new methods of mining have been successfully introduced, even in areas where aquifers were present above the seams and there was concern over the possibility of water inflow into the mines.

Finally, we have attempted in Tables 5-5, 5-6, 5-7 and 5-8 to summarize the salient facts about each mine. Table 5-5 records the principal characteristics, Table 5-6 the geological facts, Table 5-7 the mining method and in Table 5-8, geotechnical matters are summarized. It should be noted that wherever a dash or blank entry occurs, information could not be identified in the study.

TABLE 5-1

POTASH MINING METHODS - DEFINITIONS

Room & Pillar	- Conventional	- Square or Rectangular Pillars
	- Chevron	- Rooms driven at angles other than 90° to panel entries
	- Long	- Long Rooms driven parallel to each other
	- Yielding	- Using narrow pillars to yield and lower roof intact and in controlled manner
	- Caving	- Pillars mined and roof allowed to collapse
Longwall	- Caving	- Long face mined using shearer type cutting machine, chain conveyor and powered supports and roof caving in goaf
	- Backfill	- Long face mined using shearer, chain conveyor, powered supports with goaf backfilled
Shortwall	- Caving	- Long face mined using continuous miners, and conveyors, with powered supports with roof caving in goaf

Shortwall	- Yielding	- Long face mined with continuous miners, no powered supports, using narrow pillars to control roof
Shortwall	- Backfill	- Long face mined with continuous miners, no supports or yielding pillars, but goaf backfilled
Open Stoping	- Backfill	- Sub-level open stoping. Stope backfilled when mined out
Cut & Fill Stoping	- Backfill	- Standard method
Shrinkage Stoping	- Backfill	- Shrinkage stoping mined out between sub-levels, then backfilled, then mined to next sub-level
Block Caving		- Standard method
Solution		- Mined from surface boreholes

TABLE 5-2

LIST OF MINES & MINING METHODS

Canada	PCS Cory	R&P - Chevron
	PCS Allan	R&P - Long-Chevron
	PCS Lanigan	R&P - Long
	PCS Rocanville	R&P - Long
	IMC K1	R&P - Long
	IMC K2	R&P - Long
	CCP Colonsay	R&P - Chevron
	Cominco Vanscoy	R&P - Long
	PCA Saskatoon	R&P - Long
	Kalium	Solution
	PCA Penobsquis	Cut & Fill
	Denison Salt Springs	(R&P - Long + Backfill)
	BP Millstream	(R&P - Long + Backfill)
USA	Duval Nash Draw	?
	Amax Carlsbad	Shortwall (Yielding)
	PCA Carlsbad	R&P - Conv-Caving
	KerrMcGee Hobbs	R&P - Chevron
	IMC Carlsbad	R&P - Long
	Mississippi Carlsbad	Shortwall (Yielding)
	Nat. Potash Carlsbad	?
	Texas Gulf Cane Creek	Solution (of R&P)
	FMC (Trona) Green River	Longwall R&P - Conv.
U.K.	CPL - Boulby	R&P - Long-Yielding

France	MDPA - Theodore	Longwall - Caving	
	- Amelie	Longwall - Caving	Two Lifts
	- Marie-Louise	Longwall - Caving	
Italy	ISPEA - San Cataldo/Palo	R&P	
	- Realmonte	Sub Level Stoping	
	- Racalmuto	R&P	
	- Pasquasia	R&P; Block Caving	
	- Corvillo	R&P	
	- Milena	Under Development	
Spain	MDPS - Suria	R&P	
	UERT - Cardona	Sublevel Open Stope	
	UERT - Llobregat	R&P - Long + Backfill (Partial)	
	PDN - Esparza	Longwall - Caving	
USSR	Uralkali - Berezniki #1	- Room & Pillar with Long Rooms	
	#2		
	#3		
	#4		
	Solikamsk #1		
	#2		
	Novosolikamsk		
	Byeloruskali - Soligorsk #1	Longwall Caving (1 or 2 lifts)	
	#2	Room & Pillar - Long-Yielding	
	#3	Room & Pillar - Conventional	
	#4	Combinations of above	

	Ukraine - Stepnik	
	Novostepnik	
	Kalush	Room & Pillar
	Bolyn	- and
	Sivka	Shrinkage Stoping
	Novaya	
	Lvov	
	(Dombrov)	Open Pit
East Germany	Kalibetreib Zielitz	R&P - Conventional
	- Zielitz	
	Kalibetrieb Werra	
	- Unterbreizbach	
	- Merkers	Open Stoping
	- Dornoff	
	Kalibetrieb Saale	
	- Teutschenthal	R&P Conventional
	Kalibetrieb Sud Hartz	
	- Rossleben	R&P - Conventional
	- Sonderhausen	
	- Volkenroda	
	- Bleicherode	R&P Modified
	- Bischofferode	
	- Sollstedt	
West Germany	Kali u Salz	
	- Bergmannsegen - Hugo	Sub Level
	- Niedersachen - Riedel	Open Stoping
	- Sigmundshall	+ Backfill
	- Siegried - Giessen	

	- Hattorf	
	- Neuhoff - Ellers	Room & Pillar
	- Wintershail	
	- Salzdetfurth	R&P + Backfill
Brazil	Engenharia Orplan	
	- Sergipe	Under development (long R&P)
China	- 3 Underground Mines	?

TABLE 5-3

Potash Mining Methods - Distribution

Method	No. of * Mines	%	Approximate* Production Mt K_2O	Approximate* Production %
Room and Pillar - Conventional	7	8.1	2.5	7
- Chevron	4	4.7	3.0	8.5
- Long	14	16.3	10.0	28.3
- Yielding	4	4.7	1.2	3.4
- Caving	1	1.1	0.6	1.7
- Backfill	4	4.7	2.7	7.6
- Unspecified	22	25.6	5.0	14.1
Total R & P	56	65.1	25.0	70.8
Longwall - Caving	8	9.3	4.2	11.9
Shortwall - Yielding	2	2.3	1.3	3.7
Open Stoping- No Backfill	5	5.8	1.2	3.4
- Backfill	4	4.7	0.8	2.3
Total Open Stoping	9	10.5	2.0	5.7
Cut and Fill	1	1.1	0.7	2.0
Shrinkage, Stoping & Backfill	7	8.1	0.4	1.1
Block Caving	1	1.1	0.5	1.4
Solution	2	2.3	1.2	3.4

* Some mines work more than one method.

TABLE 5-4

Potash Mining Methods, Recoveries

Method		Typical % Recovery in Panel
Room and Pillar	- Conventional	50-65
	- Chevron	50-75
	- Long	55-80
	- Yielding	66
	- Caving	76
Longwall	- Caving	80-85
Shortwall	- Yielding	90-92
Open Stoping	- No Backfill	85-90
	- Backfill	80-90
Cut and Fill		80
Shrinkage Stoping & Backfill		78
Solution		100 (theoretical)

TABLE 5-5 SUMMARY OF PRINCIPAL CHARACTERISTICS OF UNDERGROUND POTASH MINES

REF. COMPANY, MINE, LOCATION	YEAR of PRODUCTION	TOTAL RESERVES (Mt)	PRESENT PROD. CAPACITY (Mt K20/yr)	PRESENT ORE CAPACITY (Mt ore/yr)	AVERAGE GRADE (% K20)	DEPTH (m)	GRADIENT (degrees)	OVERALL RECOVERY (%)	MINING METHOD	TOTAL EMPLOYEES	REMARKS
CANADA											
01 PCA - PENOBSQUIS, NB	1984	-	0.7	2.3	25	460-760	25-45	55-60	CUT & FILL	245	-
02 DENISON - SALTSPRINGS, NB	1985	230	1.0	3.6	28	835	12-20	60-65	R & P LONG, BACKFILL	-	-
03 BP - MILLSTREAM, NB	(1988)	256	-	-	22	840-1200	5-70	23	R & P LONG, BACKFILL	441	-
04 PCS - ROCANVILLE, SASK	1971	-	0.78	3.0	27	960	0.2	33	R & P LONG		
05 IMC - K1 & K2, SASK	1962/67	-	2.32	9.3	25	955	0.2	35	R & P LONG	-	-
06 PCS - CORY, SASK	1969	-	0.83	3.2	18-26	1012	0.2	38	R & P LONG CHEVRON	-	-
07 PCS - LANIGAN, SASK	1968	-	0.60	3.0	20-24.5	1006	0.2	-	R & P LONG	-	-
08 PCS - ALLAN, SASK	1968	-	0.97	3.6	27.3	1036	0.2	-	R & P CHEVRON	-	-
09 COMINCO - VANSCOY, SASK	1969	112	0.50	3.6	25-30	1076	0.2	39	R & P LONG	-	-
10 CCP - COLONSAY, SASK	1969	-	0.82	3.1	22-32	1021	0.2	35	R & P CHEVRON	-	-
11 PCA - SASKATOON, SASK	1958	-	0.42	1.6	27	1016	0.2	-	R & P LONG	-	-
12 PPG - KALIUM, SASK	1964	-	0.85	-	-	1730	-	-	SOLUTION	-	-
UNITED STATES											
01 KERR MCGEE - HOBBS, NM	1966	63.5	0.2	3.3	13-18	500	1.2	55	R$P CHEVRON	398	
02 MISSISSIPPI - CARLSBAD,NM	1931	290	0.2	2.6	14-33	260-500	1.7	-	SHORTWALL	406	on care and mtce
03 AMAX - CARLSBAD, NM	1953	-	0.5	4.1	11-19	220-340	1.1	-	SHORTWALL	-	
04 PCA - CARLSBAD, NM	1934	10	0.5	3.1	12-23	305	0.8	70	R&P, DEPILLARING	396	
05 IMC - CARLSBAD, NM	1940	-	0.3	-	10-14	215-270	1.0	-	R & P	-	
06 NATIONAL POTASH - LEA, NM	1957	-	0.2	-	14	490-550	1.0	-	R & P	-	
07 DUVAL - NASH DRAW, NM	1964	37.7	0.1	-	8-16	274-328	1.1	-	R & P	-	
08 TEXAS GULF - CANE CREEK, UT	1965 (conv) 1970(sol)	-	0.2	-	27	920	8.8	100	SOLUTION	100	
SPAIN											
01 MPS - SURIA, CATALONIA	1926	-	0.3	1.8	16.5	550-680	60-70	-	ROOM & PILLAR	-	
02 UERT - CARDONA, CATALONIA	1930	62.5	0.25	2.5	11-12	1100	20-60	66	SUB-LEVEL OPEN STOPING	680	
03 UERT - LLOBREGAT, CATALONIA	1934/1948	16.0	0.4	1.7	12-20 22.5	45	5-10	50	LONG ROOM & PILLAR CHEVRON & BACKFILL	-	
04 PDN - ESPARZA, NAVARRA	1963	-	0.325	2.8	13	200-1500	13	70	LONGWALL CAVING (ADVANCING)	-	
UNITED KINGDOM											
01 CPL - BOULBY, CLEVELAND	1973	-	0.48	1.7	25-30	1066	1 in 10	25	ROOM & PILLAR (D&B)	-	
ITALY											
01 ISPEA - SAN CATALDO/PALO, SICILY	1960 (sc) 1974 (p)	-	0.45-0.50	-	12 10-17	200	0-45	45	R & P	600	
02 ISPEA - RACALMOLTO, SICILY	1973	-	0.65	-	11	840	25	40	R & P (SUBLEVEL)	-	
03 ISPEA - PASQUASIA, SICILY	1964	-	1.0	-	14.5	825 757 310	25-30	-	R & P	-	
04 ISPEA - CORVILLO, SICILY	1967	-	0.2	-	15-17	-	-	-	BLOCK CAVING	-	
05 ISPEA - MILENA, SICILY	U.D.	-	0.5	-	-	1250	-	-	R & P	-	
06 ISPEA - REALMONTE, SICILY	1977	-	0	-	15-17	150	60-65	-	- STOPING	-	
FRANCE **MINES DE POTASSE d'ALSACE (MDPA)**											
01 AMELIE	1910	-	1.8	12.9	19	420-1100	up to 35	-	LONGWALL	-	
02 THEODORE	-1914	-		7.7	19	420-1100	up to 35	-	LONGWALL	-	
03 MARIE-LOUISE	-1914	-		14.5	19	420-1100	up to 35	-	LONGWALL	-	
GERMAN FEDERAL REPUBLIC **KALI UND SALZ AG**											
01 BERGMANSSEGEN - HUGO	-	-	0.21	1.81	11.5	350-1200	40-90	85-90	OPEN SUBLEVEL STOPING	-	
02 SALZDETFURTH	1900	-	0.25	1.96	12.5	770-900	40-90	85.90	"	-	
03 SIEGFRIED - GIESEN	1906	-	0.12	1.13	10.8	1050	40-90	85-90	"	-	
04 SIGMUNDSHALL	-	-	0.30	1.78	16.9	400-1040	40-90	85-90	"	-	
05 NIEDERSACHSEN - RIEDEL	1910	-	0.15	1.12	14.0	750-1320	40-90	85-90	"	-	
06 WINTERSHALL	1903	-	0.44	6.1	11.0	540	2-3	70	R & P	-	
07 HATTORF	1910	-	0.37	4.5	11.1	700-1060	2-3	55-65	"	-	
08 NEUHOF - ELLERS	-	-	0.31	3.2	12.0	400-600	2-3	55-65	"	-	
GERMAN DEMOCRATIC REPUBLIC **KALIBETRIEB WERRA**											
01 UNTERBRIEZBACH	-	-	0.72	-	-	-	-	50	R & P	-	
02 MERKERS	-	-		-	-	-	-	50	R & P	-	
03 DORNDORF	-	-		-	-	-	-	50	R & P	-	
KALIBETRIEB SUD HARZ											
04 ROSSLEBEN	1905	-	0.32	-	-	700	-	50	R & P	-	
05 SONDERSHAUSEN	-	-	-	-	-	-	-	50	R & P	-	
06 SOLLSTEDT	1905	-	-	-	-	-	-	50	R & P	-	
07 BLEICHRODE	1902	-	-	-	-	-	-	50	R & P	-	
08 VOLKENRODA	1909	-	-	-	-	-	-	50	R & P	-	
09 BISCHOFFERODE	1915	-	0.510	-	-	-	-	50	R & P	-	
KALI-UND STEIN SALZBETRIEB SAALE											
10 TEUTSCHENTAL	1907	-	-	-	-	-	-	50	R & P	-	
KALIBETRIEB ZIELITZ											
11 ZIELITZ	1973		0.9	5.3	17	800	18-25	50	R & P	-	
RUSSIA **URALS**											
01 BEREZNIKI NOS.1-4	1931	15900	5.2-5.3	12.3-13.1	21	300-500	-	-	DOME & PILLAR	-	
02 SOLIKANSK NOS. 1&2	1931		1.4	3.5	14-15	200-500	-	-	ROOM & PILLAR	-	
03 NOVO SOLIKANSK	1983		1.9-2.0	4.5-5.0	14-15	200-500	-	-	ROOM & PILLAR	-	
BYELORUSSIA											
04 SOLIGORSK NOS. 1-4	1963 (no.1) 1978 (no.4)	2800	5.0-5.2	11.8-12.2	13.4-17.7	420-650	5.0	80-85 OVERALL 43-45 R&P 70-75 LONGWALL	R&P, LONGWALL	16000 SURF + U/G	
UKRAINE											
05 KALUSH - STEPNIK AREA	1923 (old) 1967 (new)	2900	0.4	0.9	8-12	100-300	19-27	90.5	R & P SHRINKAGE STOPING	-	

TABLE 5-5
SUMMARY OF PRINCIPAL CHARACTERISTICS OF UNDERGROUND POTASH MINES

TABLE 5-6 SUMMARY OF PRINCIPAL GEOLOGICAL CHARACTERISTICS OF UNDERGOUND POTASH MINES

REF. COMPANY, MINE, LOCATION	GEOLOGICAL AGE	POTASH BEDS	MAIN STRUCTURE	DEPTH (m)	SEAMS NO. MINED (No. Present)	RANGE of THICKNESS (m)	AVERAGE GRADE (%)	PERCENTAGE INSOLUBLES (%)	SALT BACK THICKNESS (m)	GAS PRESENT (Y/N)	UNCONFORMITIES PRESENT (Y/N)	AQUIFERS PRESENT (Y/N)
CANADA												
01 PCA - PENOBSQUIS, NB	MISSISSIPPIAN	DUNSINANE	DOME	460-760	1 (2)	6-38	25	2.5	VARIABLE 100+	N	N	Y
02 DENISON - SALTSPRINGS, NB	MISSISSIPPIAN	MARCHBANK	BEDDED	835	1 (4)	6-30	28	1.0	10-104	N	N	Y
03 BP - MILLSTREAM, NB	DEVONIAN	CASE	BEDDED	840-1200	5 (5)	4-37	22	2.5-4.3	50-100	N	N	Y
04 PCS - ROCANVILLE, SASK	DEVONIAN	ESTERHAZY	COMPLEX BEDDED	960	1	2.4	-	-	27	N	N	Y
05 IMC - K1 & K2, SASK	DEVONIAN	ESTERHAZY	BEDDED	955	1	2.4	25	-	27-45	N	N	Y
06 PCS - CORY, SASK	DEVONIAN	PATIENCE LK (v)	BEDDED	1010	1 (3)	3.3	18-26	-	6-14	N	N	Y
07 PCS - LANIGAN, SASK	DEVONIAN	PATIENCE LK(v&l)	BEDDED	1006	2 (1)	3.4	20-24.5	-	6-14	N	N	Y
08 PCS - ALLAN, SASK	DEVONIAN	PATIENCE LK (v)	BEDDED	1036	1 (1)	3.35	27.3	-	6-14	N	N	Y
09 COMINCO - VANSCOY, SASK	DEVONIAN	PATIENCE LK (v)	BEDDED	1076	1 (1)	3.3	25-30	-	6-14	N	N	Y
10 CCP - COLONSAY, SASK	DEVONIAN	PATIENCE LK (v)	BEDDED	1021	1 (1)	3.3	27	-	6-14	N	N	Y
11 PCA - SASKATOON, SASK	DEVONIAN	PATIENCE LK (v)	BEDDED	1016	1 (1)	3.3	27	-	6-14	N	N	Y
12 PPG - KALIUM, SASK	DEVONIAN	PATIENCE LK (v) BELLA PLAINS ESTERHAZY	BEDDED	1730	4 (4)	-	-	-	-	-	-	Y
UNITED STATES												
01 KERR MCGEE - HOBBS, NM	PERMIAN	SOLADO	BEDDED	500	1 (11)	1.5	13-18	6	215	Y	N	N
02 MISSISSIPPI - CARLSBAD,NM	PERMIAN	SOLADO	BEDDED	260-500	2 (11)	1.2-1.8	14-33	3	137	Y	N	N
03 AMAX - CARLSBAD, NM	PERMIAN	SOLADO	BEDDED	220-340	2 (11)	1.2-1.5	11-19	2	140	Y	N	N
04 PCA - CARLSBAD, NM	PERMIAN	SOLADO	BEDDED	305	2 (11)	1.2	12-23	-	200	N	N	N
05 IMC - CARLSBAD, NM	PERMIAN	SOLADO	BEDDED	215-270	3 (11)	2.0	10-14	-	-	-	N	N
06 NATIONAL POTASH - LEA, NM	PERMIAN	SOLADO	BEDDED	490-550	(11)	1.7	14	-	-	-	N	N
07 DUVAL - NASH DRAW, NM	PERMIAN	SOLADO	BEDDED	274-328	2 (11)	1.2-1.8	8-16	4	-	-	N	N
08 TEXAS GULF - CANE CREEK, UT	PENNSYLVANIAN	PARADOX	COMPLEX BEDDED	920	2 (1)	0-6.1	27	2	-	Y	Y	N
SPAIN												
01 MPS - SURIA, CATALONIA	OLIGOCENE	CATALONIA	ANTICLINAL	550-680	2 (4)	2-8	16.5	-	50-70	N	N	N
02 UERT - CARDONA, CATALONIA	OLIGOCENE	CATALONIA	ANTICLINAL DOME DISTURBED	1100	1 (2)	5-20	11.5	-	50-70	N	N	N
03 UERT - LLOBREGAT, CATALONIA	OLIGOCENE	CATALONIA	BEDDED FOLDED	450	2 (2)	6.0 (mined) 0.8 p 2.0 rs 3.2 p	22.5 35 17	-	50-70	N	Y	N
04 PDN - ESPARZA, NAVARRA	OLIGOCENE	CATALONIA	BEDDED GENTLY DIPPING	200-500	1 (2)	2-15	13	-	15-120	Y	N	Y
UNITED KINGDOM												
01 CPL - BOULBY, CLEVELAND	PERMIAN	ZECHSTEIN BOULBY BEDS	COMPLEX BEDDED	1100-1200	1	5.0 1-17.0	27	5-10	0	Y	Y	Y +70
ITALY												
01 ISPEA - SAN CATALDO/PALO, SICILY	UPPER MIOCENE	SOLFIFERA	BEDDED	200	6 (1)	2-20	10-17	0.8	-	N	-	N
02 ISPEA - RACALMOLTO, SICILY	UPPER MIOCENE	SOLFIFERA	COMPLEX ANTICLINAL	840	5 (1)	3-35	11	0.8	-	N	-	N
03 ISPEA - PASQUASIA, SICILT	UPPER MIOCENE	SOLFIFERA	BEDDED UNDULATING INCLINED	300-825	5 (1)	30-35 10 3.0-5.5	14.5 11 15-17	0.8	-	N	-	N
04 ISPEA - CORVILLO, SICILY	UPPER MIOCENE	SOLFIFERA	-	-	-	-	15-17	0.8	-	N	-	N
05 ISPEA - MILENA, SICILY	PLEISTOCENE	-	-	1250	-	-	-	0.8	-	-	-	-
06 ISPEA - REALMONTE, SICILY	UPPER MIOCENE	SOLFIFERA	BEDDED ANTICLINAL STEEPLY INCLINED	150	6 (1)	5.0	15-17	0.8	-	N	-	N
FRANCE MINES DE POTASSE d'ALSACE (MDPA)												
01 AMELIE	LOWER OGLIOCENE	WITTELSHEIN	BEDDED	420-1100	2	1.2-5.0	19	15	40-60	Y	N	Y
02 THEODORE	LOWER OGLIOCENE	WITTELSHEIN	BEDDED	420-1100	2	1.2-5.0	19	15	40-60	Y	N	Y
03 MARIE-LOUISE	LOWER OGLIOCENE	WITTELSHEIN	BEDDED	420-1100	2	1.2-5.0	19	15	40-60	Y	N	Y
GERMAN FEDERAL REPUBLIC KALI UND SALZ AG												
01 BERGMANSSEGEN - HUGO	UPPER PERMIAN	ZECHSTEIN 1	SALT DOME	350-1200	2	4-30	11.5	-	-	Y	-	Y
02 SALZDETFURTH	UPPER PERMIAN	ZECHSTEIN 3	SALT DOME	770-900	2	4-30	12.5	-	-	Y	-	Y
03 SIEGFRIED - GIESEN	UPPER PERMIAN	ZECHSTEIN 3	SALT DOME	1050	2	4-30	10.8	-	-	Y	-	Y
04 SIGMUNDSHALL	UPPER PERMIAN	ZECHSTEIN 3	SALT DOME	400-1040	1	4-30	16.9	-	-	Y	-	Y
05 NIEDERSACHSEN - RIEDEL	UPPER PERMIAN	ZECHSTEIN 3	SALT DOME	750-1320	1	4-30	13.0	-	-	Y	-	Y
06 WINTERSHALL	UPPER PERMIAN	ZECHSTEIN 3	BEDDED	540	3	2.5-3.5	11.0	-	>110	Y	-	Y
07 HATTORF	UPPER PERMIAN	ZECHSTEIN 3	BEDDED	700-1060	2	1.5-3	11.1	-	>110	Y	-	Y
08 NEUHOF - ELLERS	UPPER PERMIAN	ZECHSTEIN 3	BEDDED	400-600	1	2	12.0	-	>110	Y	-	Y
GERMAN DEMOCRATIC REPUBLIC KALIBETRIEB WERRA												
01 UNTERBRIEZBACH	-	-	- BEDDED - AND - SALT DOME	-	2	-	-	-	100	Y	Y	Y
02 MERKERS	-	-		-	2	-	-	-	100	Y	Y	Y
03 DORNDORF	-	-		-	2	-	-	-	100	Y	Y	Y
KALIBETRIEB SUD HARZ												
04 ROSSLEBEN	-	-	- BEDDED - AND SALT DOME -	-	1	-	13-14	3.5	100	Y	Y	Y
05 SONDERSHAUSEN	-	-		-	1	-	-	-	100	Y	Y	Y
06 SOLLSTEDT	-	-		-	1	-	-	-	100	Y	Y	Y
07 BLEICHRODE	-	-		-	1	-	-	-	100	Y	Y	Y
08 VOLKENRODA	-	-		-	1	-	-	-	100	Y	Y	Y
09 BISCHOFFERODE	-	-		-	1	-	-	-	100	Y	Y	Y
KALI-UND STEIN SALZBETRIEB SAALE												
10 TEUTSCHENTAL	-	-	SALT DOME	-	2	-	-	-	100	Y	Y	Y
KALIBETRIEB ZIELITZ												
11 ZIELITZ	UPPER PERMIAN	-	SALT DOME	-	2	6-9	17	-	80	Y	Y	Y
RUSSIA URALS												
01 BEREZNIKI NOS.1-4	LOWER PERMIAN	-	BEDDED	300-500	4	4.7-4.8	21	0.5-3.0	-	Y	-	Y
02 SOLIKANSK NOS. 1&2	LOWER PERMIAN	-	BEDDED	200-500	4	4.7-4.8	14-15	0.5-3.0	-	Y	-	Y
03 NOVO SOLIKANSK	LOWER PERMIAN	-	BEDDED	200-500	4	4.7-4.8	14-15	0.5-3.0	-	Y	-	Y
BYELORUSSIA												
04 SOLIGORSK NOS. 1-4	UPPER DEVONIAN	-	BEDDED	420-650	2 (4)	2.0-6.1	13.4-17.7 (26.2)*	5.0-9.0 (8.54)*	-	Y	-	Y
UKRAINE												
05 KALUSH - STEPNIK AREA	LOWER TO MIDDLE MIOCEN	-	-	100-300	-	-	8-12	12-18	-	-	-	Y

TABLE 5-6

SUMMARY OF PRINCIPAL GEOLOGICAL CHARACTERISTICS OF UNDERGROUND POTASH MINES

TABLE 5-7 SUMMARY OF PRINCIPAL CHARACTERISTICS OF UNDERGROUND MINING METHODS

REF. COMPANY, MINE, LOCATION	DEPTH (m)	SEAM THICKNESS MINED (m)	GRADIENT (degrees)	MINING METHOD	PANEL LENGTH (m)	PANEL WIDTH (m)	PANEL RECOVERY (%)	PILLAR SIZE (m x m)	EXCAVATION EQUIPMENT (Panels)	TRANSPORT EQUIPMENT (ore)	DEVELOPMENT ENTRIES (No.)	DEVELOPMENT ENTRIES (m x m)	DEVELOPMENT EQUIPMENT	DEVELOPMENT TRANSPORT	OUTPUT/ DAY (tonnes ore)	UNDERGROUND MANPOWER	UNDERGROUND PRODUCTIVITY (t/man shift)
CANADA																	
01 PCA - PENOBSQUIS, NB	460-760	6-38	25-45	CUT & FILL	600	120	80	600x40	ALPINE	C/V	1	-	ALPINE	C/V	44000 (wk)	120	53
02 DENISON - SALTSPRINGS, NB	835	6-30	12-20	R & P LONG, BACKFILL	200	42	65	200x20	MANALTA (DB)	S/C+C/V	2	-	CM	S/C+C/V	69000 (wk)	150	65
03 BP - MILLSTREAM, NB	840-1200	4-37	5-70	R & P LONG, BACKFILL	450	36	40	50x450	ALPINE	C/V	4	-	ALPINE	C/V	-	255	61
04 PCS - ROCANVILLE, SASK	960	2.4	0.2	R & P LONG	1220	1220	35	-	MANALTA	C/V	5	-	MANALTA	C/V	53000 (wk)	100	91
05 IMC - K1 & K2, SASK	955	2.4	0.2	R & P LONG	1980	975	55	-	MANALTA	C/V	3	-	MANALTA	C/V	-	-	-
06 PCS - CORY, SASK	1010	3.3	0.2	R & P LONG, CHEVRON	2700	170	60	90x2700	GOODMAN MANALTA	C/V	3	10x3.4	ALPINE MANALTA	C/V	70000 (wk)	-	-
07 PCS - LANIGAN, SASK	1006	3.4	0.2	R & P LONG	1600	-	43	6;45	MANALTA	C/V	-	9.1x3.4	GOODMAN	C/V	60000 (wk)	210	-
08 PCS - ALLAN, SASK	1036	3.35	0.2	R & P CHEVRON	1000	-	-	-	-	-	-	-	-	-	-	-	-
09 COMINCO - VANSCOY, SASK	1076	3.3	0.2	R & P LONG	1800	-	58	7x200	MANALTA	C/V	3-4	5.5x3.4	MANALTA	C/V	50000 (wk)	-	-
10 CCP - COLONSAY, SASK	1021	3.3	0.2	R & P CHEVRON	1300	170	55	-	MANALTA	S/C+C/V	3	-	GOODMAN ALPINE	C/V	65000 (wk)	-	-
11 PCA - SASKATOON, SASK	1016	3.3	0.2	R & P LONG	-	-	-	-	-	-	-	-	-	-	-	-	-
12 PPG - KALIUM, SASK	1730	-	-	SOLUTION	-	-	-	-	WELLS	-	-	-	-	-	-	-	-
UNITED STATES																	
01 KERR MCGEE - HOBBS, NM	500	1.5	1.2	R&P CHEVRON	800	260	75-80	-	C.M.	S/C+C/V	3	7.6x2.0	C.M.	S/C+C/V	63000(wk)	246	55
02 MISSISSIPPI - CARLSBAD, NM	260-500	1.2-1.8	1.7	SHORTWALL	760	305	92	2.4x4.2	C.M.	S/C+C/V	3	7.9x1.8	C.M.	S/C+C/V	(50000)(wk)	(139)	72
03 AMAX - CARLSBAD, NM	220-340	1.2-1.5	1.1	SHORTWALL	1000	275	92	2.4x4.2	C.M.	S/C+C/V	4	7.3x1.5	C.M.	S/C+C/V	82000(wk)	209	78
04 PCA - CARLSBAD, NM	305	1.2	0.8	R&P, DEPILLAR	-	-	90	13.7x13.7	C.M.	S/C+C/V	5	-	PCA MINER	C/V	60200(wk)	201	60
05 IMC - CARLSBAD, NM	215-270	2.0	1.0	R & P	-	-	-	-	-	-	-	-	-	-	-	-	-
06 NATIONAL POTASH - LEA, NM	490-550	1.7	1.0	R & P	-	-	-	-	-	-	-	-	-	-	-	-	-
07 DUVAL - NASH DRAW, NM	274-328	1.2-1.8	1.1	R & P	-	-	-	-	-	-	-	-	-	-	-	-	-
08 TEXAS GULF - CANE CREEK, UT	920	0-6.1	8.8	SOLUTION	-	-	100	-	-	-	-	-	-	-	-	-	-
SPAIN																	
01 MPS - SURIA, CATALONIA	550-680	-	70-80	R & P	-	-	-	-	-	-	-	-	-	-	-	-	-
02 UERT - CARDONA, CATALONIA	1100	5-20	20-60	SUBLEVEL OPEN STOPING WET BACKFILL	SUBLEVEL LEVEL 20m	100m BLOCKS	80	-	DIB,LHD JUMBO LAYELIDE	FEEDER BREAKER CONVEYOR	4	5x3.5	DRILL/BLAST JUMBO,R/HDR	C/V	6000	360	17
03 UERT - LLOBREGAT, CATALONIA	450	6 (2x3m lifts)	5-10	R & P TWO LIFTS	ROOM 6x150	400x180 BLOCKS	50	450x3	CM (Alpine) SC	C/V	3	7x6	ALPINE 100	C/V	8000	320	25 (mined) (19) (ore)
04 PDN - ESPARZA, NAVARRA	200-1500	-	13	LONGWALL ADV	-	180-270	8"	-	6 SHEAVER AFC SUPPORTS	C/V	11xarch	-	CM RHDRS	C/V	6000	940	12.1
UNITED KINGDOM																	
01 CPL - BOULBY, CLEVELAND	1066	3.0	5	R & P	4000	66		3.66	(a) DB-drill cutters, feeder/b, LHD 12' lifts (b)1976-CM Mar&Mel S/C	CONVEYORS	6.3w x3.1m h	5	D."	-	10000	500	20 1
ITALY																	
01 ISPEA - SAN CATALDO/PALO, SICILY	200	2-20	0-45	R & P	-	-	-	-	DRILL/BLAST LOADERS S/CAIS	RAIL CONVEYOR	-	-	CM S/CARS	RAIL,C/V	-	-	-
02 ISPEA - RACALMUTO, SICILY	840	3-35	25	R & P SUBLEVEL	-	-	-	-	DRILL/BLAST JUMBO LHD	CONVEYOR	-	-	CM,SC	C/V	-	115	14.5
03 ISPEA - PASQUASIA, SICILY	310-825	3-35	25-30	R & P SUBLEVEL BLOCK CAVING	-	-	-	30x30 (S) 20x20 (C) 8m sublevels	CM,SM DRILL/BLAST JUMBO/LHD	CONVEYOR	-	-	CM,SC	C/V	-	-	-
04 ISPEA - CORVILLO, SICILY	-	-	-	R & P	-	-	-	-	-	-	-	-	-	-	-	-	-
05 ISPEA - MILENA, SICILY	1250	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
06 ISPEA - REALMONTE, SICILY	150	5.0	60-65	SUBLEVEL STOPING	-	-	-	-	DRILL/BLAST JUMBO/LHD	TRUCK	-	-	DRILL/BLAST JUMBO/LHD	C/V	-	-	-
FRANCE																	
MINES DE POTASSE d'ALSACE (MDPA)																	
01 AMELIE	420-1100	1.4-3.5	up to 35	LONGWALL	1000-1700	800	85	-	LONGWALL	CONVEYORS	2	3.9w x ore ht	RIPPER HEAD PUMES	SHUTTLE CAR & CONVEYOR	12900	104/PANEL	100
02 THEODORE	420-1100	1.4-3.5	up to 35	LONGWALL	1000-1700	800	85	-	LONGWALL	CONVEYORS	2	3.9w x ore ht			7700	-	100
03 MARIE-LOUISE	420-1100	1.4-3.5	up to 35	LONGWALL	1000-1700	800	85	-	LONGWALL	CONVEYORS	2	3.9w x ore ht			14500	-	100
GERMAN FEDERAL REPUBLIC																	
KALI UND SALZ AG																	
01 BERGMANNSSEGEN - HUGO	350-1200	-	40-90	OPEN SUBLEVEL STOPING	200 high	>100m long	85-90	6-12	DRILL/BLAST	LHD, LOCOMOTIVE CONVEYOR	-	-	-	-	-	-	45
02 SALZDETFURTH	770-900	-	40-90	"	200 high	>100m long	85-90	6-12	DRILL/BLAST	"	-	-	-	-	-	-	45
03 SIEGFRIED - GIESEN	1050	-	40-90	"	200 high	>100m long	85-90	6-12	DRILL/BLAST	"	-	-	-	-	-	-	45
04 SIGMUNDSHALL	400-1040	-	40-90	"	200 high	>100m long	85-90	6-12	DRILL/BLAST	"	-	-	-	-	-	-	45
05 NIEDERSACHSEN - RIEDEL	750-1320	-	40-90	"	200 high	>100m long	85-90	6-12	DRILL/BLAST	"	-	-	-	-	-	-	45
06 WINTERSHALL	540	-	2-3	R & P	-	-	70	-	DRILL/BLAST	LHD, CONVEYORS	-	-	-	-	-	-	55
07 HATTORF	700-1060	-	2-3	R & P	-	-	55-65	45	DRILL/BLAST	LHD, CONVEYORS	-	-	-	-	-	-	55
08 NEUHOF - ELLERS	400-600	2	2-3	R & P	-	-	55-65	-	DRILL/BLAST	LHD, CONVEYORS	-	-	-	-	-	-	55
GERMAN DEMOCRATIC REPUBLIC																	
KALIBETRIEB WERRA																	
01 UNTERBRIEZBACH	-	-	-	R & P	-	-	-	-	-	-	-	-	-	-	-	-	-
02 MERKERS	-	-	-	R & P	-	-	-	-	-	-	-	-	-	-	-	-	-
03 DORNDORF	-	-	-	R & P	-	-	-	-	-	-	-	-	-	-	-	-	-
KALIBETRIEB SUD HARZ																	
04 ROSSLEBEN	-	-	-	R & P	-	-	-	-	-	-	-	-	-	-	-	-	-
05 SONDERSHAUSEN	-	-	-	R & P	-	-	-	-	-	-	-	-	-	-	-	-	-
06 SOLLSTEDT	-	-	-	R & P	-	-	-	-	-	-	-	-	-	-	-	-	-
07 BLEICHRODE	-	-	-	R & P	-	-	-	-	-	-	-	-	-	-	-	-	-
08 VOLKENRODA	-	-	-	R & P	-	-	-	-	-	-	-	-	-	-	-	-	-
09 BISCHOFFERODE	-	-	-	R & P	-	-	-	-	-	-	-	-	-	-	-	-	-
KALI-UND STEIN SALZBETRIEB SAALE																	
10 TEUTSCHENTAL	-	-	-	R & P	-	-	-	-	-	-	-	-	-	-	-	-	-
KALIBETRIEB ZIELITZ																	
11 ZIELITZ	-	-	-	R & P	-	-	-	-	-	-	-	-	-	-	-	-	-
RUSSIA																	
URALS																	
01 BEREZNIKI NOS. 1-4	300-500	-	-	ROOM & PILLAR	3000	400	60-65	12x12	CONT. MINER	SHUTTLE CAR, FEEDER, B. CONV RAIL	3	-	CONT. MINER	SHUTTLE TO CONV.	-	-	-
02 SOLIKANSK NOS. 1&2	200-500	-	-	ROOM & PILLAR	3000	400	60-65	11x11 up to 19x19	CONT. MINER	RAILWAYS, CONV. BELTS, SHUTTLE CAR	3	-	CONT. MINER	SHUTTLE TO CONV.	-	-	-
03 NOVO SOLIKANSK	200-500	-	-	ROOM & PILLAR	3000	400	60-65	-	CONT. MINER	RAILWAYS, CONV. BELTS, SHUTTLE CAR	3	-	CONT. MINER	SHUTTLE TO CONV.	-	-	-
BYELORUSSIA																	
04 SOLIGORSK NOS. 1-4	420-650	-	-	ROOM & PILLAR LONGWALL	-	300-400	up to 76	6x6 or 10x10	CONT. MINER, TWIN DRUM RANGING SHEARER	CHAIN CONV., STAGE LOADER, B. CONV.	3	3x3	CONT. MINER	SHUTTLE CAR TO CONV.	LONGWALL- 5000-6000t/mos 24000t/mos 1200-1800/day	6000	-
UKRAINE																	
05 KALUSH - STEPNIK AREA	100-300	-	-	ROOM & PILLAR SHRINK. STOP.	-	-	-	7.7x7.7 (12x12) (6x6)	-	-	-	-	-	-	450000t/yr	-	8.14

TABLE 5-7

SUMMARY OF PRINCIPAL CHARACTERISTICS OF UNDERGROUND MINING METHODS

TABLE 5-8 SUMMARY OF PRINCIPAL GROUND CONTROL CHARACTERISTICS

REF. COMPANY, MINE, LOCATION	DEPTH (m)	MINING METHOD	SEAM THICKNESS MINED (m)	GRADIENT (degrees)	SUPPORT TYPE PANELS	SUPPORT TYPE DEVELOPMENT	STRATA CONTROL PROBLEMS	MAJOR CONCERNS	UNDERGROUND MONITORING (Y/N)	SUBSIDENCE MONITORING (Y/N)
UNITED STATES										
01 KERR MCGEE - HOBBS, NM	500	R&P CHEVRON	1.5	1.2	NONE	NONE	NONE	GAS	Y	Y
02 MISSISSIPPI - CARLSBAD,NM	260-500	SHORTWALL	1.2-1.8	1.7	NONE	NONE	NONE	NONE	Y	Y
03 AMAX - CARLSBAD, NM	220-340	SHORTWALL	1.2-1.5	1.1	NONE	NONE	NONE	NONE	Y	N
04 PCA - CARLSBAD, NM	305	R&P,DEPILLAR	1.2	0.8	RANDOM R.B.	RANDOM R.B.	NONE	NONE	Y	N
05 IMC - CARLSBAD, NM	215-270	R & P	2.0	1.0	-	-	-	-	-	-
06 NATIONAL POTASH - LEA, NM	490-550	R & P	1.7	1.0	-	-	-	-	-	-
07 DUVAL - NASH DRAW, NM	274-328	R & P	1.2-1.8	1.1	-	-	-	-	-	-
08 TEXAS GULF - CANE CREEK, UT	920	SOLUTION	0-6.1	8.8	-	-	-	-	-	-
SPAIN										
01 MPS - SURIA, CATALONIA	550-680	R & P	-	70-80	-	-	-	-	-	-
02 UERT - CARDONA, CATALONIA	1100	SUBLEVEL OPEN STOPING WET BACKFILL	5-20	20-60	RANDOM R.B.	RANDOM R.B.	NONE	NONE	Y	Y
03 UERT - LLOBREGAT, CATALONIA	450	R & P TWO LIFTS	6 (2x3m lifts)	5-10	RESIN R.B.	RESIN R.B.	NONE	NONE	RANDOM	Y
04 PDN - ESPARZA, NAVARRA	200-1500	LONGWALL ADV	-	13	RESIN R.B.	RESIN R.B.	ROCK STRESS	DEPTH: EXPL. FOR CAVING	Y	Y
UNITED KINGDOM										
01 CPL - BOULBY, CLEVELAND	1066	R & P (SR)	3.0	5	RB	RB	HIGH STRESSES	AQUIFER HEAT GAS	Y	?
ITALY										
01 ISPEA - SAN CATALDO/PALO, SICILY	200	R & P	2-20	0-45	NONE	NONE	NONE	-	-	-
02 ISPEA - RACALMOLTO, SICILY	840	R&P(SUBLEVEL)	3-35	25	NONE	NONE	NONE EXCEPT IN SHAFT	-	-	-
03 ISPEA - PASQUASIA, SICILY	310-825	R & P BLOCK CAVING	3-35	25-30	NONE	NONE	"	-	-	-
04 ISPEA - CORVILLO, SICILY		R & P	-	-	-	-	-	-	-	-
05 ISPEA - MILENA, SICILY	1250	-	-	-	-	-	-	-	-	-
06 ISPEA - REALMONTE, SICILY	150	SUBLEVEL STOPING	5	60-65	NONE	NONE	NONE	-	-	-
FRANCE **MINES DE POTASSE d'ALSACE (MDPA)**										
01 AMELIE	420-1100	LONGWALL	1.4-3.5	up to 35	PROP CHOCKS	NONE	NONE	NONE	Y	-
02 THEODORE	420-1100	LONGWALL	1.4-3.5	up to 35	PROP CHOCKS	NONE	NONE	NONE	Y	-
03 MARIE-LOUISE	420-1100	LONGWALL	1.4-3.5	up to 35	PROP CHOCKS	NONE	NONE	NONE	Y	-
GERMAN FEDERAL REPUBLIC **KALI UND SALZ AG**										
01 BERGMANSSEGEN - HUGO	350-1200	OPEN SUBLEVEL STOPING	4-30	40-90	NONE	ARCH	-	-	-	-
02 SALZDETFURTH	770-900	"	4-30	40-90	NONE	ARCH	-	-	-	-
03 SIEGFRIED - GIESEN	1200	"	4-10	40-90	NONE	ARCH	-	-	-	-
04 SIGMUNDSHALL	400-1040	"	4-30	40-90	NONE	ARCH	-	-	-	-
05 NIEDERSACHSEN - RIEDEL	750-1320	"	4-30	40-90	NONE	ARCH	-	-	-	-
06 WINTERSHALL	540	R & P	1.3-3.5	2-3	ROCK BOLTS & PILLARS	ROCK BOLT			-	-
07 HATTORF	700-1060	R & P	1.3-3.5	2-3	"	ROCK BOLT	-	-	-	-
08 NEUHOF - ELLERS	400-600	R & P	1.3-3.5	2-3	"	ROCK BOLT	-	-	-	-
GERMAN DEMOCRATIC REPUBLIC **KALIBETRIEB WERRA**										
01 UNTERBRIEZBACH	300-1000	R & P	-	-	PILLARS & ROCK BOLTS	-	-	-	Y	-
02 MERKERS	300-1000	R & P	-	-	"	-	-	-	Y	-
03 DORNDORF	300-1000	R & P	-	-	"	-	-	-	Y	-
KALIBETRIEB SUD HARZ										
04 ROSSLEBEN	700	R & P	-	-	PILLARS & ROCK BOLTS	-	-	-	Y	-
05 SONDERSHAUSEN	660-800	R & P	-	-	"	-	-	-	Y	-
06 SOLLSTEDT	570-720	R & P	-	-	"	-	-	-	Y	-
07 BLEICHRODE	630-660	R & P	-	-	"	-	-	-	Y	-
08 VOLKENRODA	1000-1033	R & P	-	-	"	-	-	-	Y	-
09 BISCHOFFERODE	630-660	R & P	-	-	"	-	-	-	Y	-
KALI-UND STEIN SALZBETRIEB SAALE										
10 TEUTSCHENTAL	730-890	R & P	-	-	PILLARS & ROCK BOLTS	-	-	-	Y	-
KALIBETRIEB ZIELITZ										
11 ZIELITZ	700-1000	R & P	-	-	PILLARS & ROCK BOLTS	-	-	-	Y	-
RUSSIA **URALS**										
01 BEREZNIKI NOS.1-4	300-500	ROOM & PILLAR	-	-	-	-	-	-	-	-
02 SOLIKANSK NOS. 1&2	200-500	ROOM & PILLAR	-	-	-	-	-	-	-	-
03 NOVO SOLIKANSK	200-500	ROOM & PILLAR	-	-	-	-	-	-	-	-
BYELORUSSIA										
04 SOLIGORSK NOS. 1-4	420-650	ROOM & PILLAR LONGWALL	-	5.0	YIELDING PILLARS HYDR. CHOCKS FITTED WITH SHIELDS	ROOF BOLTS 1.5-1.8m LONG 1.5m APART	ROOF	-	Y	Y
UKRAINE										
05 KALUSH - STEPNIK AREA	100-300	ROOM & PILLAR SHRINK. STOP.	-	19-27	-	-	-	-	-	-

TABLE 5-8

SUMMARY OF PRINCIPAL GROUND CONTROL CHARACTERISTICS

PART 6

ALTERNATIVES TO PRESENT UNDERGROUND POTASH MINING METHODS IN CANADA

PART 6 - ALTERNATIVES TO PRESENT UNDERGROUND POTASH MINING METHODS IN CANADA

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6.1 INTRODUCTION

The preceeding parts have described and summarized the various methods which are used to mine potash in underground mines in different parts of the world. We believe, as a result of our study of these methods, that there are lessons to be learnt and there are alternatives which can be applied to the Saskatchewan potash deposits in the short, medium and long term, and to the New Brunswick potash deposits in the long term.

Any alternative must, however, offer benefits over present day methods. The most tangible benefits sought are improved recovery, improved working conditions and increased productivity, all of which should lead to a reduction in operating costs.

Due to the highly competitive nature of the potash industry, no mining company has been prepared to make available any form of cost information. Evaluations of the different mining methods and their applicability to Canadian mines have thus had to be made based on such factors as recovery, productivity and conditions.

6.2 PARAMETERS FOR & AGAINST THE USE OF ALTERNATIVE MINING METHODS

Before evaluating which mining methods could be considered as alternatives to the present mining methods in use in Canada, it is first necessary to examine those factors which are both advantageous and disadvantageous in the use of alternative mining systems.

621 ADVANTAGES

The advantages that would be expected to accrue from the introduction of an alternative mining method include:

(i) Increased extraction and reserve utilization
(ii) Ability to selectively mine and improve run-of-mine product
(iii) Increased productivity
(iv) Better strata control and safety
(v) Possible lower costs
(vi) No surface tailings disposal if backfill used
(vii) Improved surface environmental conditions
(viii) Reduced rate of development
(ix) Reduced rate of capital equipment requirement
(x) Better ventilation with certain systems

Several of these are self-evident [(i), (iii), (iv) (v)] but we would comment further as follows:

Selective Mining

Most potash deposits consist of alternating layers of sylvite and halite (or carnallite and halite). Where the halite seams are in excess of 0.5 metre in thickness, this can often be either mined separately by continuous miner, roadheader or shearer and backfilled, or left in place by mining above and below, as is practised in the two lift longwall mining in the USSR. This has considerable potential benefits for improving costs, increasing output and improving ground control.

Backfill

If the waste salt tailings can be returned to the underground workings, benefits can be expected from increased ore recovery; no surface tailings disposal required with the consequential environmental problems with land use, surface and groundwater pollution, and air & noise pollution; better ground control and thus improved safety; and, if underground beneficiation (see Section 6.5.6) can be utilized, increased hoisting capacity with all the potential that entails.

Rate of Development

For the same overall output from the mine, the ability to recover more of the reserves from a given area means that it will take longer to mine out that particular area. These areas do not therefore have to be developed as quickly (a fact most mine managers would surely welcome). This then raises the possibility of diverting some of the development equipment to production and thus improve productivity further - production usually having higher productivities than development.

Capital Equipment Requirements

If the mine does not develop as fast with the alternative method, i.e. it is not expanding as fast, then it would be reasonable to expect that the requirements for capital equipment (conveyors, cables and electrical switchgear, pipes, ventilation accessories, etc.) will be reduced, thus enabling both capital and operating costs to be similarly reduced.

Ventilation

Certain mining systems such as longwall, shortwall (in certain forms), cut and fill stoping and to a lesser extent other forms of stoping, are operated with through ventilation systems, rather than the split and diverted systems common to room and pillar mining. These permit better control and improvement of heat, dust and gas, thus enabling working conditions to be improved and human and equipment efficiencies to be increased.

622 DISADVANTAGES

The major disadvantages which have to be dealt with in the introduction of an alternative potash mining method include:

i) Possible problems with mine integrity
ii) Upfront cost for research, engineering and planning
iii) High initial capital cost with certain methods
iv) Need to change present attitudes and customs
v) Need for training to operate the new method.

We would comment on these as follows:

Mine Integrity

Most mineable potash deposits seem to be associated with either aquifers and/or brine streams at some horizon above the potash seam, between the potash bed and the surface. These liquids must be kept out of the mine at all costs. With the consequent change in mining and strata behaviour, there is always an element of unknown in terms of that behaviour, no matter how many investigations, tests and modelling techniques have been applied. The proof comes from trying the method. The introduction of a new mining method does therefore have an element of risk.

Upfront Costs

Before any new method can be or should be, introduced into an existing mine, considerable exploration, research, investigation, engineering, planning and possibly trial mining has to be undertaken. This is particularly so where the mine's integrity is in question. Assessment of this cost has to balance the benefits to be gained down the road.

Initial Capital Costs

Some mining systems such as longwall mining, or the use of backfill, require high capital expenditures to establish the systems. In longwall mining, several million dollars will be required to cover the supply of the shearer cutting machine, the face conveyor and the powered supports. Where backfill is introduced, additional equipment is required to transport and place the backfill in the working faces.

Attitudes and Customs

One of the biggest barriers to be overcome with the introduction of any new method is the fact that for many people, the way it is being done now is good enough, they do not want to have to deal with the unknown. It is axiamatic that a considerable employee relations exercise will be called for, to ensure that when the time comes to introduce the new system, everyone is convinced that it will work, and will thus make every effort to ensure that it does.

Training

The introduction of new methods and equipment requires that training be provided for operating, maintenance, supervisory and management staff to ensure that the system is safely and efficiently used, and in particular that the learning curve be kept as short as is reasonable and practical.

623 CONCLUSION

It can thus be seen that the introduction of an alternative mining method is not a simple affair, but one which requires considerable financial outlay. This requires, in turn, that a full examination is made of all the benefits and disadvantages inherent in the system, so that a decision to proceed can be clearly justified.

6.3 GENERAL GEOLOGY & MINING METHODS

Potash deposits currently being worked around the world by underground methods can be very broadly divided into two categories. Those deposits which are generally flat lying, continuous and of relatively regular thickness, and those which are folded (often severely) and frequently varying in thickness. The Saskatchewan deposits are typical of the first category, whilst the New Brunswick deposits belong more clearly into the second category.

With one exception, mining methods can also be allocated by usage to one or the other of these two geological categories. For example, mining methods such as room and pillar (in all its forms), shortwall, and longwall are usually most successful in the flatter, regular, tabular deposits, whilst mining methods, such as cut & fill, sub-level stoping with backfill, shrinkage stoping and block caving have been more successfully applied to the folded variable thickness deposits. The exception is solution mining which can be applied to either category of deposit.

6.4 GEOTECHNICAL ASPECTS OF ALTERNATIVE MINING METHODS

With any mining method, there is a very close relationship between the shape, dimensions and orientation of orebodies; between the strata types and their characteristics and behaviour; and the applicability of various mining methods. It is, therefore, of importance to understand the applications and characteristics of the various mining methods, particularly from a geotechnical viewpoint.

641 ROOM AND PILLAR MINING

The room and pillar system is used almost entirely to mine flat lying deposits. It is not a practical method for seams dipping at greater than 10 to 20 degrees. The most important aspects are selecting stable and safe room spans and pillar sizes, and at the same time maximizing extraction. With a thick sequence of evaporites in the roof and an absence of clay seams, wide roof spans can be achieved even at considerable depths. For example stable spans of 18 to 26 m have been achieved in mines at depths of 1000 m with a 30 m thick salt back.

Narrow spans are required as the thickness of the saltback decreases particularly down to thickness of two to 10 m, and/or prominent clay seams are present. A further degree of conservatism is required if the salt back provides the impermeable barrier to overlying aquifers. Mechanically anchored or resin grouted rock bolts are the most common form of support used in room and pillar mining to improve the stability of the mine roof.

Pillars need to be designed to remain stable under the applied stress of the overlying formations and provide support to the roof. Typical maximum extraction ratios for stable pillar configurations are 60 to 65 percent although this can be increased to 90 percent or more where complete or partial pillar mining is possible. Pillar mining will produce significant convergence of the roof and floor and may result in caving. This becomes a particularly important design aspect if significant aquifers overlie the deposit.

A significant number of mines, particularly where the stresses are high due to the large depth below surface and the salt roof is thin with prominent clay partings, have experienced significant roof stability problems in developing narrow (6 to 10 m wide) single entries. The salt back fails in compression. Conditions can be improved by increasing the effective span, either by widening the opening or by excavating multiple parallel entries separated by thin yield pillars. Mining blocks in turn are separated by wide barrier pillars. By permitting the wide effective roof to deflect more, high horizontal compressive stresses are relieved and transferred higher into the roof where stability does not pose a problem. In the extreme, the roof of outside entries of a parallel entry system fail in a controlled manner, and the interior entries are mined under stress relieved conditions. This approach is used extensively in mines in the Saskatchewan mining district and in the U.K.

Extensive use is also made of thin yielding pillars which allow the lowering of the roof to take place in a controlled manner without rupture. This has been particularly successful in the USA, and also in the USSR under water bearing strata.

Backfill has not been used entensively in room and pillar mines for structural support, although waste salt is sometimes placed in the mined rooms. However backfill may play a greater role in the future, particularly to increase extraction in areas where convergence needs to be restricted to ensure that connection is not made to major overlying aquifers.

642 LONGWALL MINING

Longwall mining (caving) is being used successfully to mine evaporites in U.S.A., France, Spain and the U.S.S.R. It is particularly favoured in the mines in France where the seams dip at up to 35 degrees or more and/or the seam is either quite thick (greater than 3.5 m) or thin (1 to 2.3 m). Under these circumstances, room and pillar mining is not very practical.

Longwall mining provides for a very high extraction, although if the salt back is thin or contains significant clay partings, it may (with the caving system), rupture behind the mine face and the seal to overlying aquifers may be lost. One of the potash mines in Spain is using a longwall caving system under an adjacent aquifer. A thin salt back and plastically deformable clay beds provide a seal between the mine and the aquifer and to date, while there is ongoing concern about breaching the seal, longwall mining has proceeded quite successfully.

Experience in France with thin seams and longwall 'caving' systems, is that the roof lowers without rupture (i.e. no caving) even though no support is provided.

643 SHORTWALL MINING

A modified longwall, properly identified as a shortwall system, is used entensively in Carlsbad potash mines where relatively thin yield pillars are left to support the roof and control subsidence at the face. These pillars subsequently crush with the advance of the mining face. This gives a very high extraction and at the same time maintains stable working conditions at the face. This method appears to be very applicable to the conditions in the Carlsbad district where the depth below surface is not very large, the salt thickness in the back is large, and there is little or no concern about overlying aquifers. One of the mines in the Carlsbad area tried conventional longwall mining but had significant difficulties in inducing caving. The use of yield pillars alleviates this problem in that they provide for controlled convergence of the roof and floor.

At one of the mines in the Esterhazy district of Saskatchewan, a further modification to shortwall mining is being investigated in detail. In this they propose to use 'longwall' advance methods and place salt tailings progressively into the mined out areas. The tailings will be placed very tight to the back by mechanical means and will be placed at optimum moisture content to maximize stiffness. While the salt back is reasonably thick and uniform, the mine is overlain by several aquifers and it is proposed that the backfill will provide progressive support to the back and provide a significant limit to convergence.

644 SOLUTION MINING

Solution mining of potash has been applied successfully to a mine in U.S.A. and one in Saskatchewan. No major geotechnical problems have been reported from these mines. Potential problems relate to the degree of control that can be maintained in the size and shape of the excavations that are created. Uncontrolled procedures may result in major sudden collapse of the overlying formations at one extreme, or result in operational problems in maintaining the stability of the wells at the other. The maintenance of the hydrostatic head is of prime importance.

To minimize well drilling, it is desirable to have separate injection and production wells and develop a connection between them. This has been found to be difficult in potash because while fractures can be propagated under pressure by hydrofracturing the formation, these tend to seal again because of the creep properties of the potash. This problem is not encountered with a single well for injection and production.

The solution mine in U.S.A. was developed after major stability problems were experienced in operating a conventional underground mine and the old workings were used as a migration path between injection and production wells. This approach has considerable potential in recovering potash from other mines once conventional mining is no longer economic, provided surface subsidence and other environmental factors do not pose any problems.

645 CUT AND FILL MINING

This type of mining is applicable to seams dipping at approximately 50 degrees or more and preferably where the orebody is of moderate width. It has not been used extensively for potash mining although is the proposed method for a new mine in New Brunswick. There is a strong potential for reasonably large hanging wall movements as it converges onto the fill, particularly with extensive mining on strike, and hence aquifers in the hanging wall may represent a problem under some circumstances. Most steeply dipping orebodies are within a salt dome or have undergone considerable folding and thickening. Hence they normally have a thick evaporite cover in the hangingwall, and roof conditions are quite stable.

In most cut and fill mining, it is not necessary for the fill to have specific strength and stiffness properties, provided that equipment and machinery can travel on it without difficulty. Cut and fill mining generally proceeds from a number of different levels at the same time so that stopes progress upwards towards previously mined and filled areas. As the crown or sill pillar between two stopes becomes smaller, the stresses in the pillar become higher and higher. Mining of the crown pillar, or at least up towards the overlying stopes generally requires careful geotechnical planning and consideration.

Cut and fill mining often competes with open stoping, particularly where the orebody is of moderate width. The main difference between the two in geotechnical terms is that because of entry of personnel, the stability of the stope backs in the cut and fill stopes needs much more detailed consideration than for the open stopes.

646 OPEN STOPING

Potash is mined by sub level open stoping method in West Germany, Italy and Spain. In most cases the stopes are backfilled although in others they remain open. The size and length of stopes is dictated by the nature of the hanging wall and footwall strata. The need for, and the timing of the backfilling of the the stope, is similarly dictated.

6.5 THE SASKATCHEWAN POTASH MINING ALTERNATIVES (Short and Medium Term)

651 BACKGROUND

These operations have been described in detail in Part 3 of the report, but for convenience, we have summarized the salient points.

- Deposit - Tabular, generally flat or low gradients
- Depth - Ranging from 960 m to 1130 m

- Mining Method - Modified forms of Room & Pillar - Longroom or Chevron with stress relief
- Recovery - Overall 33-38%; Panel 55-62%
- Major Problems - Presence of Dawson Bay member aquifer above seam; Severe distortion and squeeze due to stress

At the time when most of the Saskatchewan potash mines were brought into production (1962 - 1970) the only method being used to conventionally mine tabular potash deposits was the room and pillar system. These operations were however being carried out at lesser depths than the Saskatchewan mines.

Under normal circumstances, room and pillar mining would not be considered at depths of around 1000 m because of rock pressure, and the resulting large pillars needed to provide adequate support. Large pillars and restricted width openings lead to overall recoveries as low as 30 percent and when taken with the creep characteristics of the potash salts and the resultant strata failure and rapid closure of rooms, modifications were needed in short order.

The presence of the Dawson Bay member at the top of the Salt Series inhibited possible use of the longwall caving system of mining, and resulted in the present long room, stress relieved system of mining. Even with these improvements, overall recovery is still below 40% with panel recoveries generally around 55% (Table 6-1).

We have considered the mining methods used elsewhere in the world, and on the basis of the need for improved recovery of reserves, reduced costs, improved conditions and better environmental control, we are confident that other methods could be applied to the Saskatchewan potash deposits in the short/medium term, and to both the Saskatchewan and New Brunswick deposits in the long term.

TABLE 6-1

Percentage Recoveries in Potash Mining Panels

Longwall Mining	- France	85%
	- Spain	80%
	- USSR	76%
	- USA (Trona)	81%
Room & Pillar	- Canada (Sask)	58%
	- USA	80%
	- West Germany	62%
	- Spain	68%
	- USSR	60%
Shortwall	- USA	92%

However, we also firmly believe that any new mining system must, in the majority of circumstances, incorporate some form of backfill into the mining operation to control and maintain the integrity of the thin saltback cover, and must be associated with a detailed geotechnical assessment.

With this in mind, the candidates for an alternative mining system in the short/medium term are:

(1) Shortwall Retreat Mining
   (a) with yielding pillars
   (b) with backfill
   (c) with yielding pillars and backfill

(2) Longwall Retreat Mining with backfill

These are the only mining methods which are not being used in Saskatchewan and which are suitable for mining the flat bedded deposits present there.

We have discussed the implications and possibilities for each method in the following sections.

652 SHORTWALL MINING

We find many people are confused about the difference between the shortwall and longwall systems of mining. The most readily identifiable difference is that a shortwall system is a long face at 90° to the panel entries, being mined by a continuous miner type machine, whilst the longwall system is a similar long face mined by a drum type shearer loader or a plough. This is the convention we have used in this report.

Shortwall mining has only been applied, to date, to two potash mines in New Mexico, one with yielding pillars, the other with yielding pillars and partial backfill (30%). In the first instance, the yielding pillars (1.8 to 2.4 m wide) are left every 11 to 18 metres of face retreat. These pillars which are eight to nine metres long and have four metres mined gaps between them, gradually crush as the strata weight is taken, allowing the roof to lower without fracture over the 300 metre working width of the panel. The thickness of the salt back at these mines is of the order of 135 metres, and in most cases, the roof convergence reaches stability some 0.5-0.6 metres above the floor (i.e. convergence represents some 60-70% of the extracted height).

In the second case, waste salt mined as part of the extraction process is simply dumped on the floor in the previously mined 'room'. This salt does not assist with the control of roof convergence until some considerable distance back from the working face (of the order of 300 metres). Roof convergence is again limited to about 60% of the extracted seam height.

None of the Saskatchewan potash areas has salt back thicknesses approaching those of New Mexico, but we believe that, following suitable geotechnical tests (see Part 7), the shortwall system of mining could be a safe and viable alternative in Saskatchewan.

To be more specific, for the Esterhazy area, a system with either yielding pillars or backfill should be capable of being safely worked under the 14-30 m thick saltback generally found in that area. Both forms of support serve a similar role. Yield pillars provide direct support to the roof close to the actual mining face, crushing and yielding as the face moves away, but subjecting the saltback to high point loading. Backfill provides support further away from the actual mining face but that support is distributed over the whole saltback. In addition, backfilled panels enable better control to be maintained of ventilation.

Part of the support system selection will be based on the consideration of the critical width which can remain open before support is provided. The smaller the critical width (10-15 m) the more likely that yield pillars will be required. If the critical width approaches 30 m, then backfill alone may suffice.

In the Saskatoon area, where the saltback is less, 6-14 m, backfill alone, with its greater critical width, is unlikely to be sufficient. Either yield pillars and/or backfill are thought to be necessary.

In all cases, the two most important questions to be addressed are: (1) will safety be affected by any stability problems with the immediate roof; and (2) will the regional movements of the roof be controlled sufficiently to prevent potential ground water inflows.

Typical layouts, without dimensions, since these will be dependent on individual mine conditions and the results of geotechnical tests, are shown in Figures 6-1, 6-2 and 6-3. Backfilling, which is expected to be either mechanical or pneumatic is dealt with in more detail later (Section 6.5.4).

As Table 6-1 illustrates, very high panel recoveries are possible with the shortwall system of mining.

We also believe that once the shortwall system has been successfully introduced, consideration should be given in the Saskatchewan area to the sequential working of both the A and B beds.

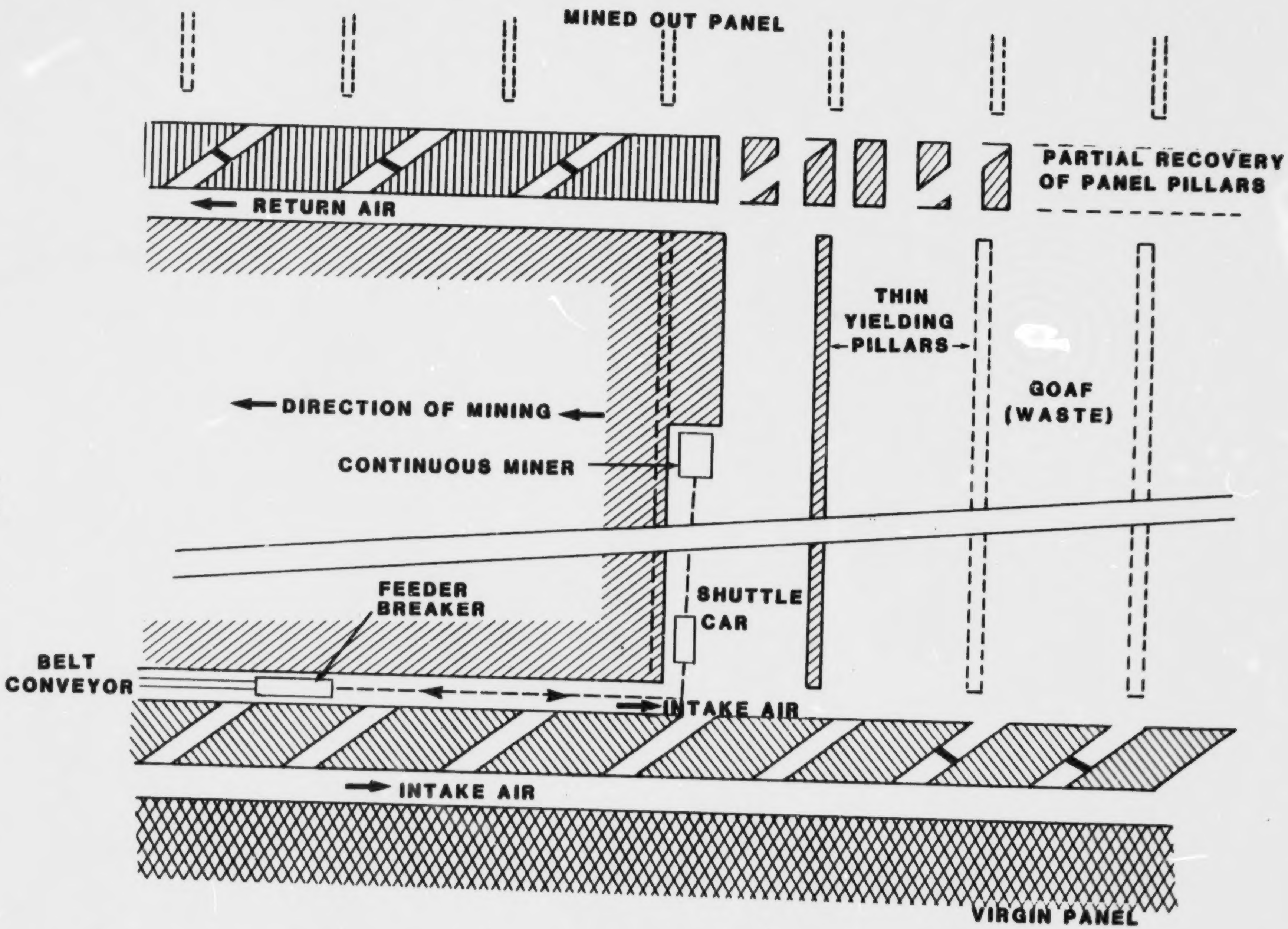
MINED OUT PANEL
PARTIAL RECOVERY OF PANEL PILLARS
RETURN AIR
THIN YIELDING PILLARS
GOAF (WASTE)
DIRECTION OF MINING
CONTINUOUS MINER
FEEDER BREAKER
SHUTTLE CAR
BELT CONVEYOR
INTAKE AIR
INTAKE AIR
VIRGIN PANEL

FIGURE 6-1 SHORTWALL MINING WITH YIELDING PILLARS (TYPICAL SCHEMATIC)

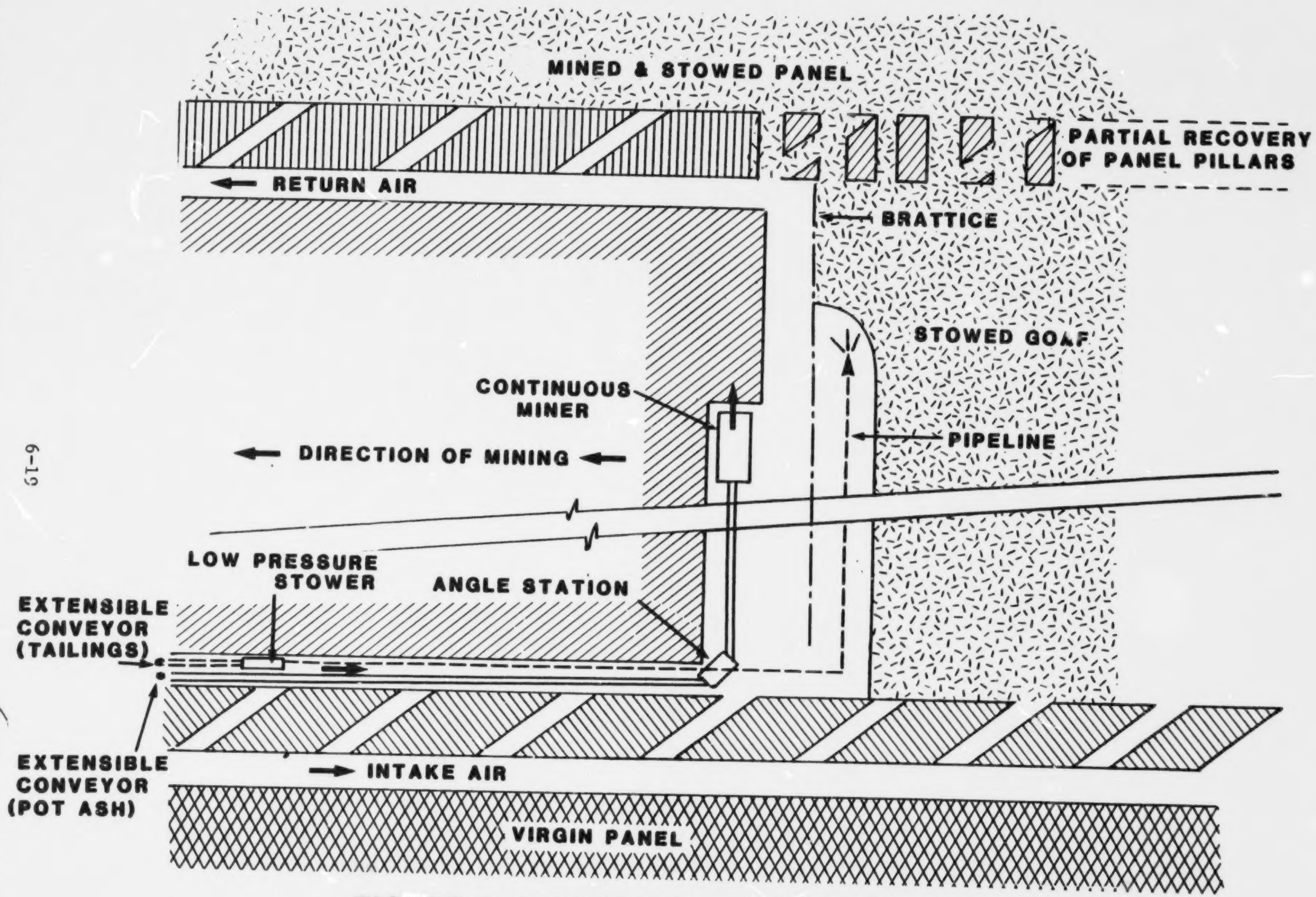
MINED & STOWED PANEL
PARTIAL RECOVERY OF PANEL PILLARS
RETURN AIR
BRATTICE
STOWED GOAF
CONTINUOUS MINER
PIPELINE
DIRECTION OF MINING
LOW PRESSURE STOWER
ANGLE STATION
EXTENSIBLE CONVEYOR (TAILINGS)
EXTENSIBLE CONVEYOR (POT ASH)
INTAKE AIR
VIRGIN PANEL

FIGURE 6-2. SHORTWALL MINING WITH BACKFILL
(TYPICAL SCHEMATIC)

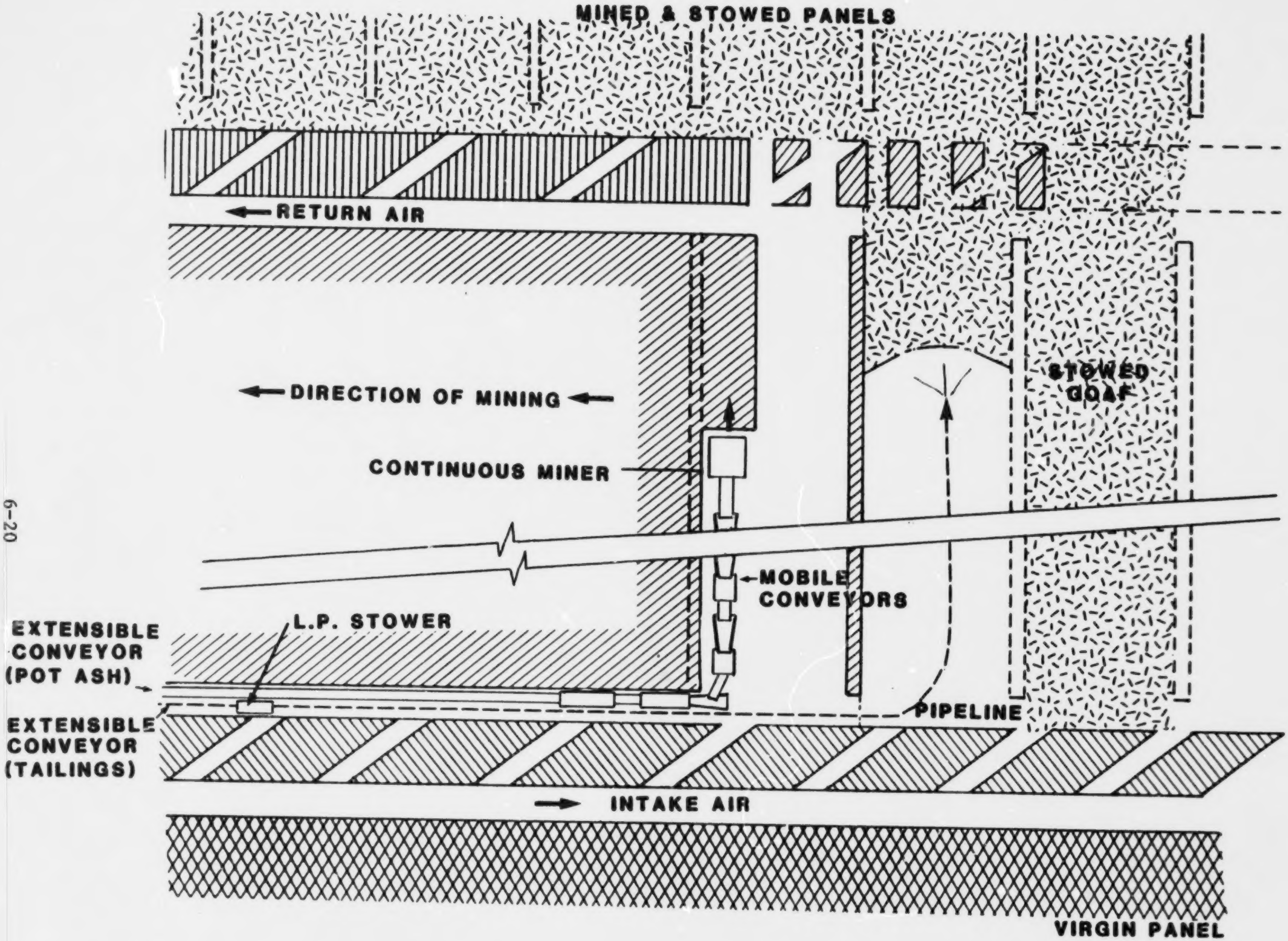
MINED & STOWED PANELS
RETURN AIR
DIRECTION OF MINING
CONTINUOUS MINER
MOBILE CONVEYORS
STOWED GOAF
L.P. STOWER
EXTENSIBLE CONVEYOR (POT ASH)
EXTENSIBLE CONVEYOR (TAILINGS)
PIPELINE
INTAKE AIR
VIRGIN PANEL

FIGURE 6-3 SHORTWALL MINING WITH BACKFILL & YIELDING PILLARS (TYPICAL SCHEMATIC)

The Mississippi mine in New Mexico, currently on care and maintenance was just beginning to work two seams four metres apart by sequential shortwall with yielding pillars, and at the Amax mine, the #3 seam is being worked by shortwall some 11 metres above the previously worked out #1 seam (R&P conventional) without any detrimental effect on stability and roof control. Initial tests that have been conducted in one of the mines in Saskatchewan indicate a significantly higher degree of stability in the underlying excavations than was experienced during the mining of the initial overlying excavations.

The percentage recoveries using the shortwall system are up to 60% better than those in the modified room and pillar systems used in Saskatchewan (Table 6-1).

653 LONGWALL MINING

In the coal mining industry, which also originally evolved with the room and pillar system, longwall mining has become by far the most prolific system, especially as mines became deeper, as equipment capabilities improved and as more knowledge was gained into the strata behaviour around longwall advancing and retreating faces. Even in the United States, long the bastion of room and pillar mining, longwall mining is beginning to carve out a significant percentage of underground mining tonnage - particularly in the deeper mines.

In the potash mining industry, longwall mining is now the sole producing method used by MDPA in France, PDN in Spain and at certain of the U.S.S.R. mines. In both France and Spain, the mines initially worked the room and pillar system, but low recoveries and low productivities led to the introduction of the longwall system, and its subsequent complete takeover of production.

Both the French and Spanish mines operate the longwall retreating total caving system, in spite in the latter case of water bearing strata above the potash beds. The integrity of the mine is however maintained because the considerable thickness of strata (140 m) between the potash and the aquifers contains many clay beds which it is believed help to seal the fissures created in the caving and subsiding strata immediately above the working faces. As the Russians have demonstrated, longwall caving is safe under aquifers provided the thickness of the intervening strata is at least forty times the extracted seam height.

The percentage recoveries in the longwall systems are up to 50% better than those in modified room and pillar systems as the Table 6-1 illustrates.

The longwall operations in France are at similar depths (1100 m) to the northwestern Saskatchewan operations whilst those in Spain (800-1200 m) are approaching both southeastern and northwestern Saskatchewan operations.

A further interesting fact to emerge from the French retreating operations in the thinner seams (one to two metres) is that the salt roof behind the longwall faces does not cave, but bends so that it reaches the floor, intact, some 30 m behind the face. This is achieved without undue stress on the face and the powered supports.

In most longwall operations, the maximum distance above the extracted seam to which the strata breaks on a fully caved longwall face is about five times the seam height extracted. At this stage, the collapsed rock has filled the void created by the extraction of the mineral and begins to provide support to the intermediate beds allowing then to lower, en masse as shown in Figure 6-4. In northwestern Saskatchewan potash, where approximately 3.4 metres is mined, this

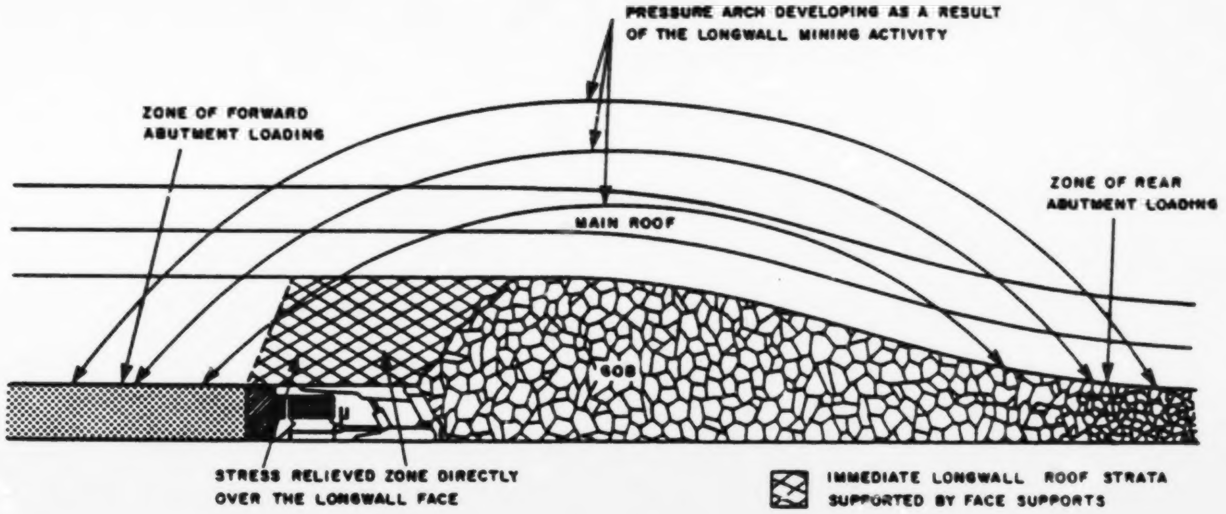
PRESSURE ARCH DEVELOPING AS A RESULT OF THE LONGWALL MINING ACTIVITY
ZONE OF FORWARD ABUTMENT LOADING
ZONE OF REAR ABUTMENT LOADING
MAIN ROOF
GOB
STRESS RELIEVED ZONE DIRECTLY OVER THE LONGWALL FACE
IMMEDIATE LONGWALL ROOF STRATA SUPPORTED BY FACE SUPPORTS

FIGURE 6-4 CROSS SECTION THROUGH AN ACTIVE LONGWALL PANEL

potash, where approximately 3.4 metres is mined, this would indicate that up to 17 metres of salt/shale could be required to cave to provide the necessary rear abutment support. In southeastern Saskatchewan, the thickness would be 12 metres. Since, however, the salt back or thickness between the potash seam roof and the Dawson Bay aquifer values from 6-14 metres in the N.W. and in the S.E. around 14 metres, the use of caved longwall systems is certainly not attractive in the N.W. and unlikely in the S.E. potash fields. This may not, however preclude the use of longwall retreating with backfill in S.E. Saskatchewan.

654 SOLID STOWING

In the U.K. in particular, and to a lesser extent in France, Germany and India, longwall mining has been worked at very shallow depths, or under bodies of water, or under urban areas where caving and the resulting massive subsidence cannot be allowed for safety reasons (both on surface and underground). In these circumstances, the void behind the face supports is stowed solid with imported material (process plant tailings, underground waste rock, or sand). When properly stowed, the stowed material prevents the roof from breaking and caving, controlling the lowering of the roof beds as the stowed material is further consolidated by roof pressure. The use of solid stowing does not prevent roof (and surface) subsidence from taking place, but the magnitude of that subsidence is greatly reduced.

An example of the effective control to be obtained using solid stowing can be seen in Table 6-2 where for identical seam extraction heights and similar longwall face and panel lengths and depths, the subsidence measured on the surface (as a percentage of the extracted seam height) is given.

TABLE 6-2

Maximum Subsidence with Stowing

	Maximum Subsidence (% of height mined)
Longwall Face - Total Caving	90%
Longwall Face - Mechanical Stowing	59%
Longwall Face - Pneumatic Stowing	47%
Longwall Face - Hydraulic Stowing	30%

Hydraulic stowing can be seen to be the most effective, but is not suitable for use in flat lying deposits, nor one suspects would it be welcome in a potash mine.

Mechanical stowing (by belt flinger or similar machine) is not as efficient as low pressure pneumatic stowing as it does not achieve the same degree of compaction (stiffness) or placed density. However each system has its advantages and disadvantages and further investigation is required into perfomance, cost and safety aspects.

655 SUPPLY AND TRANSPORT OF STOWING MATERIAL

The operation of any mining system with backfilling of the mined excavation, requires a source of backfill and a transportation system to take that fill material from the source of supply. This operation is commonplace in many metal mines. In potash mining, backfill is used extensively in West Germany in the steeper deposits, and in the new potash mines operating and being developed in New Brunswick. In all cases, the source of backfill is the mill tailings (salt) which usually contains between 5% and 8% moisture. This is sent down the shaft through a drop pipeline and transported by belt conveyor (usually slung under the conveyor transporting the potash ore out of the mine) to the stope or face to be filled. In the steeper deposits, fill is placed by gravity, but in the flatter deposits some form of pneumatic or mechanical stower is used.

In some mines, USSR in particular, some of the backfill comes from either development drivages in waste rock or it is specially mined from the waste rock.

The whole question of the sourcing, transportation and handling of backfill requires further investigation. Whilst at almost every potash mine, there is on the surface a huge spoil heap of salt tailings, it is unlikely that this will be disposed of back underground, since the tailings generated from current production will be more readily available. However, as mines are at present designed, all the ore (potash and salt) is transported underground and hoisted to the surface. With a backfill system in operation, over 75% of the same material has to find its way back underground again. The obvious cost effective answer is to keep the waste salt underground.

656 UNDERGROUND BENEFICIATION

Studies recently carried out for the U.S. Bureau of Mines have investigated the feasibility of carrying out a primary separation of coal and waste rock underground in coal mines.

The study looked at the current and developing practices in coal cleaning technology and concluded that not only could certain techniques be safely operated underground, but that taking into account the cost savings of not hoisting the rock, of the potential for increasing the capacity of the mine, and the cost of backfilling, the operation would be economical.

With the possible exception of Western Germany, the majority of potash processing plants are 'wet' processes and thus not likely to be acceptable underground in potash mines. However, in Western Germany, considerable use is being made in the surface process plant of a 'dry' separation process known as 'electrostatic' separation.

Electrostatic beneficiation or separation is a completely dry process. The crushed and ground sylvinite is conditioned to achieve greater retention of the electrostatic charge by heating to dryness at

300°-700°C and possibly coating the crystals with an organic reagent such as a fatty acid or a salt, ester or amine derived from it.

The ground ore is then electrostatically charged by friction in a vibrating trough, the potassium chloride becoming negatively charged and the halite positive. Separation of the two minerals occurs when the crystals fall under gravity between two vertical plates with a potential difference of several thousand volts per centimetre between them. The inevitable unseparated fraction is reconditioned and recycled. As in the flotation process, the impurities carried within the structure of the potassium chloride crystals will not be removed.

We believe that the ability to carry out a primary separation of the potash and salt in an underground located process plant has considerable attractions, and that electrostatic precipitation and separation is a prime candidate for use to do that.

Further investigation is obviously required to determine, not only the suitability of the process for handling both Saskatchewan and New Brunswick run of mine ores, but also to establish the safety and suitability of the process for operations in an underground environment.

6.6 THE NEW BRUNSWICK POTASH MINING ALTERNATIVES
(Short & Medium Term)

The first potash mine in New Brunswick started production this year (1984) and the other two mines under development are expected to start commercial potash production in 1985 and hopefully before 1990 respectively.

The mining methods being employed or planned in these potash beds of greatly varying thickness and gradient range from cut and fill stoping, to conventional room and pillar, and long room and pillar both with backfill.

It is reasonable to assume that the management of these mines has taken into account the latest state-of-the-art methods for mining those areas of the mine expected to be extracted in the first 10 years of the mine life, and it would be presumptious of us, in this brief review, to suggest that there are better methods available. At the very least, the geotechnical behaviour of the strata under mining conditions has to be determined.

However, we do expect that changes will have to be made in the medium term (10-30 years) since the geological structure of the deposit to be mined in the medium term is expected to change drastically. For instance, we expect cut and fill stoping may be replaced by possibly shortwall or longwall or Vertical Crater Retreat (VCR) mining, all with backfill. Similarly, long room and pillar may be replaced by cut and fill, VCR and fill, or sub-level open stoping and backfill. In each case, the choice of method will depend on (amongst other factors) seam thickness, gradient, roof (hanging wall) and floor (footwall) characteristics and salt back thickness.

6.7 SASKATCHEWAN POTASH MINING OPERATIONS AND POSSIBLE ALTERNATIVES (Long Term)

671 SOLUTION MINING

We have already discussed the mining methods which could be alternatives to present underground mining of potash, and we envisage that these alternative methods will enable the mines to continue extracting potash until they have economically mined out their permit area.

At this point in time, we believe that the potash remaining in the mine in pillars and unmined seams can be recovered by applying solution mining to the underground mine.

This is already being successfully accomplished by Texasgulf at their Cane Creek mine in Utah. This mine started life as a conventional room and pillar mine, but following geological and economical difficulties, was converted to a solution mine. This successful operation has been described in more detail in Section 4.2.

Simply stated (but not necessarily simple in practice), the operation consists of taking all equipment out of the mine and sealing the mine; drilling wells from the surface into the old workings at preselected points; flooding the mine, and then (after a suitable standing time in the mine) pumping out the potash rich brine through the production wells, whilst replenishing the brine with water through the injection wells. Since the brine is denser than water, production wells are usually in the lower parts of the mine. The success of the operation is, however, very dependent on the ability of the solution to dissolve the potash from the pillars underground, a process which can be complicated by the presence of insolubles and carnallite (magnesium). A considerable amount of research is required to establish the basic parameters of the solution mining process and its application to each particular mine. This is the one mining method about which almost no information is publicly available.

Whilst, there may appear to be plenty of time available to assess this potential method, we believe that an investigation into the solution mechanisms, an evaluation of the likely cost benefits and an investigation of potential regional stability problems should be commenced at an early date.

6.8 NEW BRUNSWICK POTASH MINING ALTERNATIVES (Long Term)

We do not believe that it is realistically possible to comment on long term possible alternative mining methods for use in New Brunswick, bearing in mind the early stage of the development of the potash field. However, with the regulatory requirement that all salt tailings shall be backfilled or disposed as brine into the ocean, final recovery by solution mining is likely to be difficult and probably uneconomical.

6.9 GEOTECHNICAL FACTORS AFFECTING USE OF ALTERNATIVE MINING METHODS IN CANADA

Because of the very close relationship between the shape, dimensions, and orientiation of orebodies and the applicability of various mining methods, it is difficult to discuss this aspect in completely general terms. Instead, the major geotechnical factors affecting the potential use of alternative mining methods are discussed for the three major potash districts in Canada.

691 EASTERHAZY - SASKATCHEWAN (Short Term)

The most important geotechnical characteristics of the potash deposits in this area are that the mining seam is flat lying and reasonably deep, approximately 1000 m; the salt deposits in the roof are reasonably uniform without prominent clay seams and are reasonably thick, approximately 30 m; and a number of aquifers are present above the salt back. Because of the presence of aquifers, major disruption of the hangingwall would likely result in unsafe conditions. There have already been some movements in the roof as a result of present extraction, which demonstrates that at these levels of movements, the 30 m uniform salt back deforms plastically and maintains an impermeable barrier between the mining seam and the overlying aquifers.

As noted earlier, the most likely alternative mining methods are shortwall retreat mining and longwall retreat mining with backfill. With extensive geotechnical studies, it may be possible to demonstrate that the salt back will remain intact and flow plastically, even with complete convergence of the roof and floor. In terms of present thinking however, this would represent a major departure from existing practice of restricting all major movements of the hangingwall. Because of this, and all of the associated uncertainties, any increase in extraction in the mines will need to incorporate yield pillars of a suitable size to control regional hangingwall movements and/or the placement of salt backfill in the mined areas to limit convergence as much as possible. To achieve the desired results, it will be necessary to place the backfill as close to the back as physically possible and to develop a backfill of maximum possible stiffness. It is not likely to be practical to compact the fill mechanically. However, by determining the optimum moisture content to achieve maximum density and stiffness through placement, recrystallization, and drainage, it seems likely that an option fill can be developed.

692 SASKATOON - SASKATCHEWAN (Short Term)

Most of the general comments that were made for the Easterhazy District are also applicable to the Saskatoon District. The major difference between the two districts is that the salt back in the

Saskatoon District is relatively thin, ranging from approximately 6 m to 15 m and it contains a number of prominent clay seams. This along with a slight increase in depth, has meant significantly more difficulties in maintaining the stability of the backs than in the Easterhazy mines.

It is almost inconceiveable to increase extraction in the Saskatoon mines or new mines in the area without using backfill. Even with backfill, the deformations in the back are likely to be significantly greater than presently occur and disruption of the impermeable salt back seal is a distinct possibility. Water inflows from the Dawson Bay limestone have already been experienced with present levels of mining. The chances of this occuring with greater extraction, even with the placement of backfill, are greatly enhanced.

If it can be demonstrated in the future that increased extraction can be achieved with backfill, it seems likely that in order to ensure safe roof conditions at the working face, and not have major slabs falling from the back, yield pillars will be required in addition to the fill.

693 NEW BRUNSWICK (Long Term)

Comments presented here are restricted to the mine that has recently commenced production using the cut and fill system. The average dip of the orebody of 45 degrees and the thick evaporite deposits in the hangingwall and footwall mean that the cut and fill system is likely to be close to the optimum mining method for this deposit in terms of safety and economy. No major geotechnical problems are anticipated, particularly at the presently proposed mining depths.

If future areas are encountered where the orebody dips more steeply, sublevel open stoping may be adopted. From a geotechnical point of review, this would be a very satisfactory mining method. To achieve maximum extraction, the mined voids would be backfilled. Cement may be added to the backfill placed in the primary stopes so that the vertical fill wall would remain stable while the adjacent pillar is completely mined. Alternatively it may be found that the fill undergoes natural compaction and consolidation through drainage and recrystallization to permit mining immediately adjacent to it without excessive ore dilution. Another alternative is to leave a thin solid potash skin between the backfill and the mined pillar. The stability of a vertical fill wall or a solid potash skin next to the fill would require further geotechnical investigation if this type of sublevel stoping with maximum extraction was considered. Apart from this, no significant geotechnical problems are anticipated.

If areas are encountered where the dip of the orebody is significantly flatter than 45 degrees, cut and fill mining may not be appropriate as presently undertaken. The combined span of the exposed hangingwall and the back of the stope would become very large as the dip decreases, and mining the steeply angled footwall contact would be difficult. Room and pillar mining may also prove impractical unless the dip is less than 10 to 20 degrees.

Longwall mining with backfill placement however, is likely to be technically feasible. The hangingwall may be too competent to cave in a controlled manner in a traditional longwall sense. The hangingwall is also likely to be sufficiently competent that yield pillars are not required to maintain local stability of the roof. Backfill will be necessary, however, to avoid massive disruption and uncontrolled caving of the hangingwall.

PART 7

GEOTECHNICAL PROGRAM

PART 7 - GEOTECHNICAL PROGRAM

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7.0 GEOTECHNICAL PROGRAM

7.1 INTRODUCTION

Before any alternative mining method is introduced within an existing mine, a thorough examination of the geotechnical factors which will control the behaviour of the mine and its constituent rocks will have to be undertaken. There will also, of course, be many other aspects - equipment, costs, manpower, training - which will also have to be examined in depth, but these fall outside the scope of this part of the study.

It will also be appreciated that the geotechnical program will have to be developed for the specific mine, and for the specific alternative method which is to be used in that mine.

With this in mind, we have stated the major elements which should form the basis of a geotechnical program, recognizing that certain elements will have greater or less emphasis placed on them in accordance with specific site conditions. We have offered comment on these major elements, and have included additional comments specifically related to the likely needs of the major potash areas in Canada.

7.2 MAJOR ELEMENTS OF A GEOTECHNICAL TEST PROGRAM

A geotechnical program to assess whether an alternative mining method can be safely and successfully introduced should include most or all of the following major elements.

721 CHARACTERIZATION OF HANGINGWALL AND FOOTWALL

(i) Saltback thickness.

(ii) Hangingwall stratigraphy, including presence of clay seams and gas.

(iii) Characterization of overlying strata.

(iv) Footwall stratigraphy.

722 ASSESSMENT OF GROUNDWATER HYDROLOGY CONDITIONS

(i) Presence and location of aquifers.

(ii) Distribution of fluid bearing zones.

(iii) Fluid pressures and permeability of aquifers.

723 GEOTECHNICAL ASSESSMENT OF HISTORICAL MINING

(i) Pillar designs (solid, yielding), roadway/room spans.

(ii) Behaviour of immediate roof and floor around workings.

(iii) Vertical limits of ground movement above workings.

(iv) Convergence and subsidence measurements.

(v) Creep characteristics of roof, floor and walls.

(vi) Regional and local stability, including seismic aspects.

(vii) Computer modelling and back analysis.

724 CHARACTERIZATION AND EVALUATION OF BACKFILL

(i) Backfill sources and handling methods.

(ii) Composition and physical parameters of backfill.

(iii) Methods of placing backfill.

(iv) Properties of placed backfill.

(v) Laboratory and in-situ mine tests.

725 GEOTECHNICAL ASSESSMENT OF ALTERNATIVE MINING METHODS

(i) Criteria for and design of solid and yielding pillars, openings including roadways and long faces.

(ii) Behaviour of immediate roof around working faces/panels (up to five times extracted height).

(iii) Limits of ground movement effect above working areas.

(iv) Prediction of convergence and subsidence effects.

(v) Prediction of load bearing capacity and rate of load acceptance for backfill (if used).

(vi) Projections for regional stability.

(vii) Computer modelling and analysis.

Each of these is discussed in more detail below in terms of the methodology to collect the required geotechnical data, and the application of that data to assess the geotechnical implications of the alternative mining method.

7.3 METHODOLOGY AND APPLICATION OF GEOTECHNICAL DATA

731 CHARACTERIZATION OF HANGINGWALL AND FOOTWALL

The aim is to determine the geological and geotechnical conditions in the hangingwall (roof) and footwall (floor). Detailed information is required of the roof within approximately fifty times the intended height of extraction, and of the floor within ten times the intended extraction height; and general information is required of the more distant strata lying above the aforementioned detailed roof information up to surface.

In the immediate roof (five to ten times extracted height) it is important to know the thickness of the salt back; the location, continuity and thickness of clay bands and other impurities, and the strength, deformation and structural characteristics of the strata.

This data can be obtained using geophysical techniques such as electrical, sonic and radar, and by drilling. These activities will generally be undertaken from underground locations although surface drilling, surface geophysics and geophysical measurements in surface drillholes may be justified in some circumstances. Drillholes should generally be cored, all core being logged and photographed. Special precautions and techniques obviously need to be used where drillholes may penetrate high pressure liquids and/or gases.

The data obtained from the drilling will provide spot information to assist with the calibration and interpretation of the geophysical measurements (radar, sonic, etc.) which can then be applied in a more widespread manner.

Laboratory tests for uniaxial compression and modulus of deformation should be carried out on core samples of the sedimentary rocks of the roof and floor of the evaporite deposit. Laboratory uniaxial and, in some cases, triaxial creep tests should be conducted on samples from the hangingwall and footwall. The creep tests are primarily index tests to assess the variation in the behaviour of the salt over the proposed mining area. They may also provide a preliminary understanding of the strength and deformation response of the salt for input into the numerical analyses (described later).

The characteristics of the strata beyond the 'immediate' category that need to be determined include the location and thickness of any soft clay layers that may form impermeable barriers to potential water inflows; the presence of extremely stiff beds that may attract high stresses and then fail with significant energy release; and the orientation and nature of joints and faults that may influence groundwater flows towards the mine. This information will be obtained from boreholes drilled on the property and from data collected during the sinking of the shafts.

In addition, data will also be sought on the presence, location, composition and pressure of any gas in the seam or strata above and below the seam, and the possibility of outbursts of gas.

732 GROUNDWATER HYDROLOGY

The most important aspects which require investigation are the location and characteristics of aquifers both adjacent to the mining seam and between that seam and the surface; and the presence or otherwise of impermeable beds that may prevent groundwater inflows into the mine. Initial assessments will be made from both available regional hydrological data; information collected during shaft construction; and historical inflows or hydrological problems that may have been experienced in the mine.

Where groundwater inflows pose a threat to safe mining, hydrological testing from underground drillholes should be conducted. This may require specialized drilling and testing equipment and procedures. Investigation should include fluid pressures; aquifer continuity over large areas; presence of isolated pockets of water, the extent to which an aquifer is plugged with salt; potential of recharge to the aquifer; and whether the water is fresh or saturated with brine.

In certain circumstances, piezometers may be installed in holes drilled into the aquifer and monitored during controlled measured inflows from a separate borehole. It is important that the pressure and characteristics of the aquifers are proven, not just surmised.

733 GEOTECHNICAL ASSESSMENT OF HISTORICAL MINING

A comprehensive compilation and review should be made of all geotechnical observations and measurements that have been made in the mine. This will form the basis for developing the parameters for the analyses and for the back analyses of the observed and measured response of the mine. These analytical models can then be used to predict the behaviour of pillars and the roof and floor of openings.

This data should include measurements of convergence over time; extensometers subsidence; stress changes; and observations of pillar and roof slabbing and spalling, and floor heave. This information should be supplemented by results from strength, deformation and creep laboratory tests.

Representative sections of the mine in which measurements and observations have been made, and where the geometry is suitable for analysis, should be identified. Analyses should be conducted and attempts made to match the observed and analyzed response of the roof, floor, pillars and openings. In this way, analysis techniques linked to the actual response of the mine should enable criteria to be established for the design of stable roof and pillar conditions.

734 BACKFILL

Whilst the most likely source of backfill will be salt tailings, other potential sources such as salt from excavations formed in the mine outside the potash seams and sand, should be identified. Other sources of backfill become necessary if the volume of available salt tailings is insufficient to fill the mined void. This is most likely to be the case in the richer potash seams.

Once the potential sources have been identified, laboratory tests should be undertaken to determine the composition, density, moisture content, compactability, and where relevant the rate of recrystallization.

A test program should be established to evaluate the available methods for stowing the fill in the underground workings, including the effects of differing methods of transporting the fill. For each method, the properties developed by the stowed fill in relation to variations in its composition. Its initial moisture content, the rate at which the fill material drains, and the method of stowing should be evaluated.

Apart from the initial preliminary tests which are required to develop stowing techniques and provide a basic understanding of the drainage and recrystallization of the fill, stowing trials should take place underground in an environment similar to the proposed mining conditions. Sample cores should be taken from the stowed material at various locations and times, in order that the physical properties of the fill, such as density, stiffness, strength, moisture content and the extent and nature of recrystallization can be determined.

Using mechanical or pneumatic stowing equipment, the fill should be stowed solid to the roof of the excavation so that it can begin to provide support to the roof as quickly as possible after the mining has taken place. The mining trials and tests should identify the fill material and stowing method which provides the most economical operation and the stowed material with the maximum stiffness.

Core samples should be obtained from the stowed material and subject to strength and stiffness tests. These should include uniaxial and triaxial tests, conventional consolidation tests, measurement of axial deformation, and creep determination.

Field programs should be established through which the strength and stiffness of the backfill can be regularly measured on a quality control basis during actual mining. These programs may include penetration resistance tests (as used in soil mechanics) or rebound tests such as the Schmidt hammer. This will enable empirical relationships between simple field tests and laboratory tests to be established.

It may also be of interest to carry out tests to establish the capabilities of the consolidated backfill to contain fluid inflows in the event that fractures in the roof strata connect with aquifers. The consolidated backfill may prove sufficiently homogeneous to seal inflows off from the open mine workings.

735 GEOTECHNICAL ASSESSMENT OF ALTERNATIVE MINING METHODS

Analyses are required to predict the stability and integrity of the mine for the alternative mining method. The type of analyses required will depend to a large extent on the success obtained and the degree of confidence developed in back analysing the historically observed and measured behaviour of the underground formations. The analyses may involve relatively simple analytical techniques or be based on comprehensive computer formulations such as finite element, finite difference and displacement continuity analyses. These analyses will incorporate consititutive relationships to model the creep response of the salt and potash formations.

Detailed analyses should be made of the stability and formation response around individual openings in addition to regional analyses to predict the mine wide response of the pillars and roof, and the support provided by the backfill (where used).

Some of the factors that need to be considered include:

- The stress at the edge of stable pillars and abutments should not exceed the critical limit at which excessive fracturing and spalling develops.

- Yield pillars should remain stable for a sufficient period of time to provide local integrity to the roof in those areas where personnel require entry.

- Convergence rates are such that the fill compresses and provides support to the roof and the equivalent roof spans do not exceed critical widths.

- Deformations in the roof do not rupture the salt back and overlying formations, causing major collapse and/or groundwater inflows.

- Regional deformations in the roof do not result in environmental problems associated with surface subsidence or ground water aspects.

- The influence of the rate of face advance on pillar and roof stability, particularly in terms of whether there is time for the high stresses at the edge of excavations to be relieved by the creep process before the next cut is made, should be assessed.

7.4 SPECIFIC ASPECTS RELATING TO CANADIAN POTASH REGIONS

Alternative mining methods are most likely to be introduced into an existing mine where a reasonably detailed understanding of the geotechnical setting and behaviour of the mine exists and is documented. The geotechnical program that is then undertaken will relate to the specific geotechnical characteristics of the mine and the characteristics of the alternative mining method. For this reason, a brief discussion is presented below for each of the Canadian potash mining districts, together with a brief examination of the geotechnical aspects relevant to the application of solution mining to a conventionally mined out mine.

741 SASKATCHEWAN - ESTERHAZY DISTRICT

The most likely alternative mining methods to those presently being used are a form of shortwall or longwall mining incorporating yielding pillars and/or backfill.

The thick salt roof between the mining horizon and the overlying Dawson Bay limestone plays an important role in providing a seal between possible overlying aquifers and the mine. It is important that the thickness of the salt roof, typically up to 30 metres, can be determined over the proposed mining area, since the alternative mining methods are likely to introduce significant changes to the mine panel and regional geometry. To date, vertical displacements of up to 50 centimetres have been measured over extended areas in the potash mines in the Esterhazy district, and these have not resulted in adverse mining conditions. However, the distribution and pressure of water bearing horizons in the Dawson Bay limestone is not known, and one of the aims of the drilling program would be to clarify this position, and hopefully to demonstrate that water inflows into the mine do not present a significant hazard.

The salt roof in the Esterhazy mines contains little or no clay. Clay seams have a potentially significant impact on the stability and behaviour of the immediate roof strata, and a further purpose of the drilling program would be to delineate the composition of the roof strata.

742 SASKATCHEWAN - SASKATOON DISTRICT

In the Saskatoon district, the salt back in the roof is thinner and contains more prominent clay seams than in the Esterhazy district. The chosen alternative mining method, likely, will require a greater degree of support to the roof than for the Esterhazy district mines.

This concern is reflected in the methods identified in Part 6 as potential alternatives. However, the same need exists to identify the nature of the aquifers in the Dawson Bay, and the distribution of clay seams in the immediate roof. These clay seams result in lateral movements of pillars and abutment walls as a result of the creep responses of the potash, and cause the immediate salt roof to fail in a compression and buckling mode. The roof in the Saskatoon mines is thus correspondingly less stable than that of the Esterhazy mines. The stability analyses will, therefore, need to be correspondingly more detailed for the Saskatoon mines.

743 NEW BRUNSWICK

Mining of the potash in New Brunswick only began in 1984 with one mine which proposes to use the cut and fill method. The use of alternative methods is not yet under consideration, but the present indications from the geological interpretation are that the form and structure of the deposit changes at depth to such an extent that, in the medium to long term, alternative mining methods will have to be considered and used. The same problem also appears to be present with the other two properties under development.

It will obviously be of benefit to future mine planning and evaluation of the alternative mining methods, if a detailed geotechnical program is initiated at these mines in order that the behaviour of the mine, both locally and regionally can be measured and observed, and models developed to help predict the strata response for that mine.

744 SOLUTION MINING OF CONVENTIONALLY MINED-OUT POTASH MINES

This form of mining takes place from wells drilled from the surface into the now abandoned underground workings. Geotechnical considerations are restricted to those associated with surface subsidence and massive roof caving. One of the most critical factors will be maintaining control over where the potash is dissolved, particularly since there will be hydraulic connection over the whole mined area. Lack of control may lead to roof collapse. Consideration has to be given to the location of the wells in relation to the underground workings, in order to reduce potential caving hazards.

Environmental concerns are also important, and studies may be required into the potential disruption of aquifers and of the potential for sudden caving to the surface. Computer models will should be developed to predict the rate of increase of cavities during the solution mining. Present models have been developed primarily to deal with solution mining in virgin ground.

PART 8

CONCLUSIONS

8.0 CONCLUSIONS

This study has reviewed the geology, geotechnology and the mining methods being used to produce potash from underground deposits around the world. In the 10 countries surveyed, including Canada, some eight different basic methods were identified. If variations within a basic method are included, then over 14 different methods are in use.

Mining methods used in Saskatchewan are predominantly variations of room and pillar mining with recoveries restricted by the need to maintain and control the immediate roof strata. Panel recoveries in Saskatchewan are amongst the lowest currently found around the world.

Most other mining methods enable higher panel recoveries to be achieved. In several of these, the roof is maintained intact through the use of yielding pillars or backfill.

In mines where backfill is used, it has been proved both practical and economic to transport backfill underground for placement in the workings, and especially in the U.K. where subsidence is considerably reduced.

Experience in the USSR, U.S.A., France and Spain has shown that mining methods can be successfully changed from low recovery systems such as room and pillar to high recovery systems such as shortwall and longwall mining. In all cases, extensive geotechnical research and trial mining was first undertaken to ensure that the change was properly controlled and the integrity and safety of the mine never threatened.

Taking cognizance of the thin salt backs and the suspected presence of aquifers in the Dawson Bay member, we have, as a result of our study, reached the following conclusions:

1. It is feasible to change to a completely different mining system.

2. It should be possible to improve the recovery of potash resources by applying shortwall or longwall methods, suitably adapted to control the lowering of the roof strata without caving.

3. The use of backfill has distinct advantages including better roof control, reduced subsidence, underground disposal of tailings, and better reserves recovery.

4. Before any alternative method can be introduced, a more detailed analysis of the characteristics of that method is required related to the specific site conditions to which it is to be applied.

5. A geotechnical test program, including characterization of the adjacent formations, laboratory testing, computer modelling and in-situ trials, should be prepared in detail for each specific site and mining method, and executed.

6. The primary separation of potash and salt underground in the mine through electrostatic precipitation suggests further possibilities for cost reduction and increased productivity and output.

7. We have not been able to reach any conclusions on the costs of operating the various methods of mining, since cost data was

not made available to us. However, in view of the highly competitive nature of the potash industry, we consider it realistic to state that it is unlikely that the changes from room and pillar mining to longwall and shortwall mining in other countries would not have become permanent unless the overall economics were favourable.

8. We do not foresee the need for consideration of alternative mining methods in the New Brunswick potash field for at least ten years, at which time, it is likely that underground conditions will begin to physically change (gradient, depth, seam thickness). We believe that consideration of such potential changes to be premature in this study.

9. Finally, in the longer term, the conversion of the conventionally mined and mined out underground mines to a solution mine is apparently very feasible, thus enabling the bulk of remaining potash (left in pillars) to be recovered. This method should be more successful than the standard solution mining technique practised from the surface, since there is not the problem of creating and maintaining the connection between injection and recovery wells.

PART 9

RECOMMENDATIONS

9.0 RECOMMENDATIONS

The primary objective of the study was to review the state-of-the-art of underground methods of mining potash around the world and identify potential alternatives for use in Canada.

The study has identified several potential methods, and also the need for more detailed information about these methods, and how they could be applied, particularly to the Saskatchewan mines.

We, therefore, make the following recommendations for the further work we consider necessary to enable a full and proper evaluation to be made of the selected alternative mining methods.

1. A more detailed examination should be made of the techniques, methods and controls used in other countries where the basic mining method has been drastically and successfully changed. We refer particularly to the Byelorussia mines in the USSR, the Alsace mines in France, the Navarra mine in Spain and the Carlsbad mines in New Mexico.

2. A detailed study should be made of the critical characteristics and operating parameters of the following alternative mining methods:

    (i) Shortwall with yield pillars

    (ii) Shortwall with backfill

    (iii) Shortwall with backfill and yielding pillars

    (iv) Longwall with backfill

(v) Longwall with caving

3. The development of a detailed geotechnical program for relating the specific conditions at mines in both the Saskatoon and Esterhazy regions, with the specific characteristics of the various alternative mining methods.

4. A feasibility study to carry out a detailed comparison of selected alternative mining methods for a selected mine in the Saskatoon region, and a selected mine in the Esterhazy region.

5. A study of the properties and behaviour of salt tailings backfill; of the various methods of placing backfill; and of the characteristics of the placed fill.

6. A study of the electrostatic precipitation system of potash beneficiation and of its potential operation in an underground environment.

7. Preliminary studies should be undertaken to assess the application of solution mining to existing conventional underground mines, with particular reference to the composition and temperature of injected and recovered fluids, potash dissolution rates in the mine, retention times in the mine, and the process modifications required to treat the brines recovered from the mine.

APPENDIX A

QUESTIONNAIRE

Monenco

POTASH MINING QUESTIONNAIRE

COMPANY ....

MINE ....

1. SEAMS

A. POTASH SEAMS NUMBER ☐ NUMBER MINED ☐

	THICKNESS (m)	DEPTH (m)	AVERAGE GRADE K_2O	GRADIENT %
WORKING SEAM #1				
WORKING SEAM #2				
WORKING SEAM #3				
WORKING SEAM #4				
WORKING SEAM #5				

B. STRUCTURE

- BEDDED ☐
- DOME ☐
- SIMPLE ☐
- COMPLEX ☐
- OTHER - PLEASE SPECIFY

C. RECOVERY

	NO BACKFILL	WITH BACKFILL
IN MINING PANEL	%	%
OVERALL	%	%

D. GEOLOGY

Please supply stratigraphic section and geological cross sections showing seams, interseam strata and regional structure.

2. MINING METHOD

Room & Pillar - Conventional Square Pillar ☐
- Long Room ☐
- Angled Room ☐
- No Pillar Extraction ☐
- Pillar Extraction ☐

Longwall - Advancing ☐
- Retreating ☐
- With Backfill (Stowing) ☐

Shortwall - No Pillars ☐
- With Pillars ☐
- With Backfill ☐

Cut & Fill ☐

Solution Mining ☐

Open Stoping ☐

Stoping with Backfill ☐

Other - Please Specify _______________________________

If backfill used, state source of fill _____________________.

Please supply plans, sections, sketeches showing mine layout and method of working.

Comments on methods used. _

_ _

_ _

3. MINING EQUIPMENT

A. DEVELOPMENT - Number of Entries ☐

		Number	Type	Model/ Capacity
Drill/Blast -	Drill			
	Cutter			
	Loader			
	Shuttlecar			
	Crusher			
	Conveyor			
	Rail Wagon			
	Locomotive			

Continuous Miners	Borer Type		Ripper Head Type
Number			
Type			
Model			
Cutting Power		kw	
Max. Cutting height		m	
Max. Cutting width		m	
Capacity		tonnes/hour	

		Borer Type		Ripper Head Type
Shuttle Cars	Number			
	Type			
	Model			
	Capacity		tonnes	
Shuttle Cars	Number			
	Type			
	Model			
	Capacity		tonnes	
Crusher	Type			
	Model			
Conveyor	Width		mm	
	Capacity		tonnes/hr	
Bolter	Number			
	Type			
	Model			

B. PRODUCTION

Room & Pillar

	Number per Section	Total in Mine
Drills		
Cutters		
Loaders		
Borer Miners		
Ripperhead		
Shuttle Cars		
Bolters		
Crushers		
Conveyors		
Other		

Longwall Number of Longwalls

Shearer - Type Model
kw Cutting Speed m/s

Face Conveyor - width kw
Capacity tonnes/hour

Supports Type Model
Rating tonnes
Number

Crusher Type Model
kw

SOLUTION MINING

Number of wells Diameter mm
Injection wells
Recovery wells

4. PRODUCTION AND STATISTICS

Number of Persons Employed - Total
- Surface
- Underground

Output - Shifts worked per week
- Ore produced per week tonnes
- Percentage or from development %
- Percentage ore from production %

Manning - Number of men per development team (including maintenance)
Specify _ _ _ _ _ _ _ _ _ _ _ _
_ _ _ _ _ _ _ _ _ _ _ _
_ _ _ _ _ _ _ _ _ _ _ _

- Number of men per production team (including maintenance)

  Specify _ _ _ _ _ _ _ _ _ _ _ _

  _ _ _ _ _ _ _ _ _ _ _ _

  _ _ _ _ _ _ _ _ _ _ _ _

Productivity

Output per manshift - overall tonnes

- underground tonnes

Costs

Operating cost per tonne undergroung (ore delivered to storage bins on surface)

Cost of handling backfill (if any)

Working Time

Number of working shifts per day

Hours per shift hrs

Number of working days per week

Number of crews

Available working time at face hrs

5. GENERAL DATA

Ventilation

- Total Quantity
- Flow per panel
- Is methane present
- Average content %

Power	- Main supply voltge ☐ kV	
	- Equipment Voltage ☐ V	

Dust Control - What dust suppression methods are used.
State briefly _ _ _ _ _ _ _ _ _ _ _ _ _
_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _
_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

Equipment Availability - What is availability of equipment ☐ %

- What percentage of available working time, does equipment actually work ☐ %

Maintenance - What is frequency of: -
Regular Maintenance ☐

Major overhaul ☐

Product Size (Mined) What is approximate size of product as mined. _ _ _ _ _ _

6. MINE PLANS AND SKETCHES

Copies of mine plans, methods of working with sufficient detail to show how mine is worked would be appreciated.

7. GEOLOGICAL

A. What is general structure of deposit and of the occurrence of potash within the deposit?

B. What is the size and extent of the deposit and the depth of the potash zones within the deposit?

C. How many mineable zones have been encountered and what are their stratigraphic positions?

D. What unusual features (if any) are present within the mining interval?

E. What reserves have been established and what is the classification of the reserves (proven, etc.) and their location?

F. How much drillhole information has been generated on the property, and what is the nature of the data?

G. What is the extent of the surface and underground geophysical survey work?

H. Are any geological cross-sections and plans available?

I. How does the exploration method impact on the mining method and vice versa?

J. What is the current operational experience with regards to lateral continuity of mineable zones consiering the influence of such factors as:

a) salt horses
b) 'wash out' phenomena
c) natural caverns

K. What variations have been noted in insolubles in the potash zone, laterally and vertically?

L. What grade variations have been experienced either through changes in potash mineralogy or percentages of K_2O content?

M. What variations are documented on the thickness of the salt back?

8. GEOTECHNICAL

A. Are there any other mines or old workings within 10 km?

If yes, what is closest distance to present mining.

_ _

B. Host Rock

- Typical rock type, thickness and sequence from 50 m above mining horizon to 50 m below (provide rough sketch if appropriate)?

- Is any one particular seam essential for safe mining?

Yes ☐ No ☐

If yes, please describe briefly

_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

C. Ground Water Hydrology

- Are there significant aquifers above mining horizon?

  Yes ☐ No ☐

  If yes, how far are they above mining seam?

- What is the thickness, location above mining seam and rock type of aquiclude above mining seam presenting ground water inflow?

- What is minimum acceptable cover to aquifers and similar restrictions?

- Are there presently ground water inflows?

  Yes ☐ No ☐

  If yes, what is approximate flow rate?

  Please briefly describe nature and circumstances of inflow.

- Were inflows experienced in the past?

  Yes ☐ No ☐

  If yes, what was average approximate flow rate?

  Please briefly describe nature and circumstances of inflows.

- Were any ground water or other stability problems experienced during shaft construction?

  Yes ☐ No ☐

  If yes, please describe briefly (including method of shaft construction).

D. Strata Control

- Pillar geometry ☐

  Square? ☐ Dimensions?

  Rectangular? ☐ Dimensions?

  Dip (rib) pillars? ☐ Dimensions?

Strike pillars? ☐ Dimensions?

Others? ☐ Please describe including dimensions.

- Dimensions of typical spans between pillars?

- Design criteria for pillars

  Based on general experience? ☐

  Based on rock mechanics assessments? ☐ Please describe criteria briefly.

- Are barrier pillar used in addition to regular pillar layout?

  Yes ☐ No ☐

- For mines with variable mining depths, do pillar sizes change with depth? Yes ☐ No ☐

- Is backfill placed in mined stopes?

  Yes ☐ No ☐

  If yes:

  Type of backfill?

Method of placement?

- What type or rock reinforcement is used in openings?

None? ☐

Mechanically anchored rock bolts? ☐

Grouted (cement or resin) rock bolts? ☐

Friction bolt? ☐

Steel sets? ☐

Shotcrete? ☐

Other? ☐ Please specify

- If rock bolts are used

Random bolting? ☐

Pattern bolting? ☐ Spacing?

Typical bolt length?

- Please describe briefly any routine strata monitoring methods that are used (e.g. convergence monitoring, extensometers)?

- What is typical long term convergence rate (convergence/unit time) in mined out areas?

E. Regional Stability

- Are surface subsidence measurements made?

Yes ☐ No ☐

If yes, what is maximum subsidence recorded from original surface elevation?

- Does surface subisdence represent a present or potential problem?

Yes ☐ No ☐

If yes, please describe briefly.

- Apart from surface subsidence, is there any other evidence of movements or disruption of the overlying strata (e.g. seismic activity, change in permeability)?

Yes ☐ No ☐

If yes, please describe briefly.

F. Others

- Is gas emitted from the deposit?

  Yes ☐ No ☐

  If yes, are emissions ever violent (blowouts)?

  Yes ☐ No ☐

- Does moisture in ventilation air affect rock strength or cause any other problems?

  Yes ☐ No ☐

  If yes, please describe briefly.

9. OTHER MINING METHODS

1. How do present mining methods differ from those used in past times?

2. Why were changes made?

3. Has recovery or productivity increased and how?

4. Are you considering any new mining methods? Elaborate.

10. MAJOR PROBLEMS

1. What are present problems which may lead to need for new mining methods? (Mining, Geotechnical, Mechanical, Electrical, Other).

2. Are you trying new solutions, if so what do you prefer?

3. In your mine, which aspects - ventilation, strata, power, hoist capacity, manpower, etc. - are likely to affect the introduction of new systems?

11. TECHNICAL JOURNALS

Please identify relevant technical articles which have been published about the mine.

APPENDIX B

REFERENCES

REFERENCES

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General	1
Canada	3
U.S.A.	8
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